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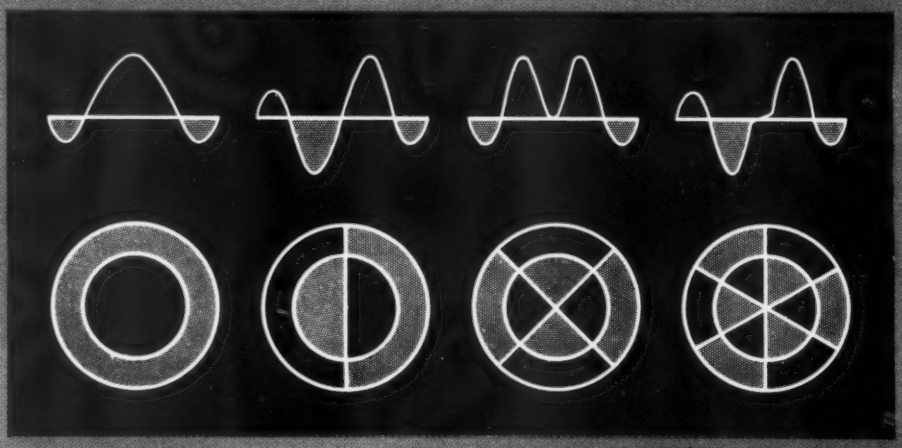
# Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · RADIATION



## Instability and control

## CEGB reactors

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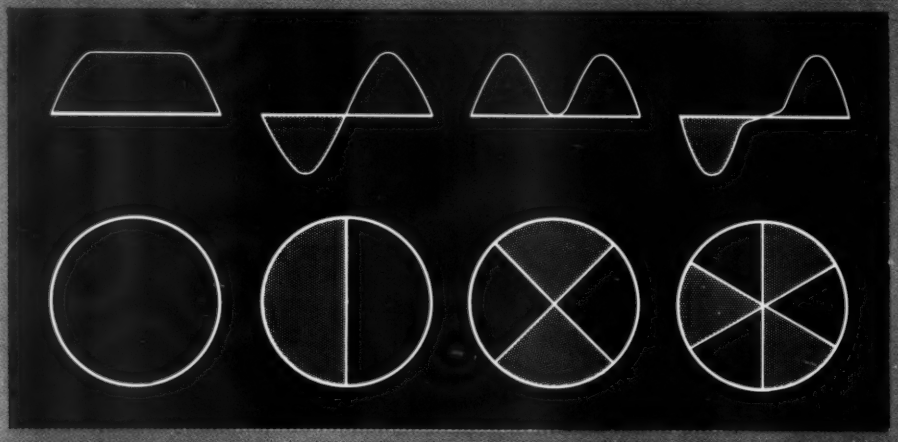

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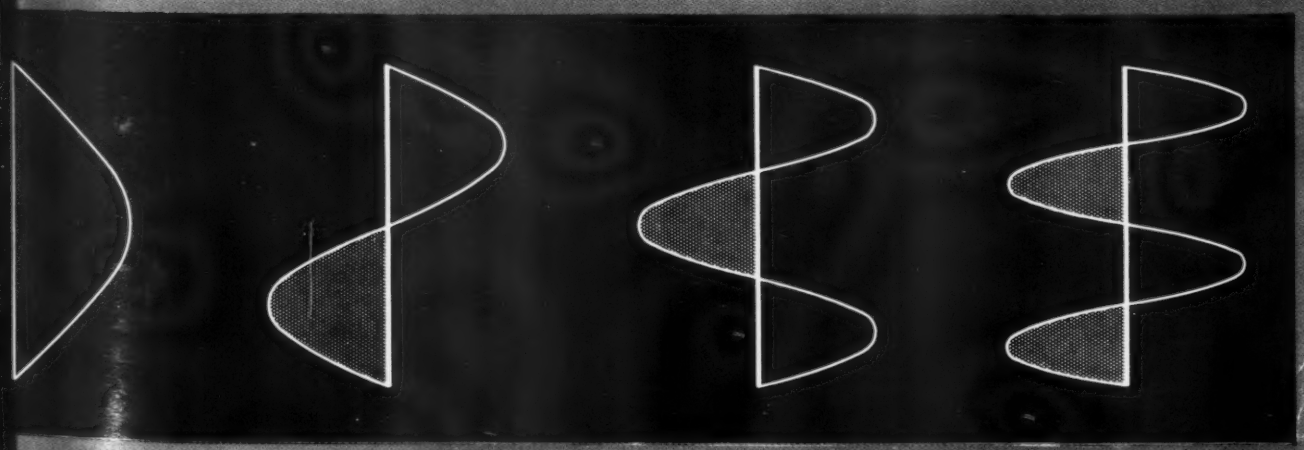
power reactor survey



May 1962 monthly 2/6

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# Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · RADIATION

VOL 5 NO 49 MAY 1960



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LOOKING FOR A JOB? SEE PAGE 164 AND ONWARDS



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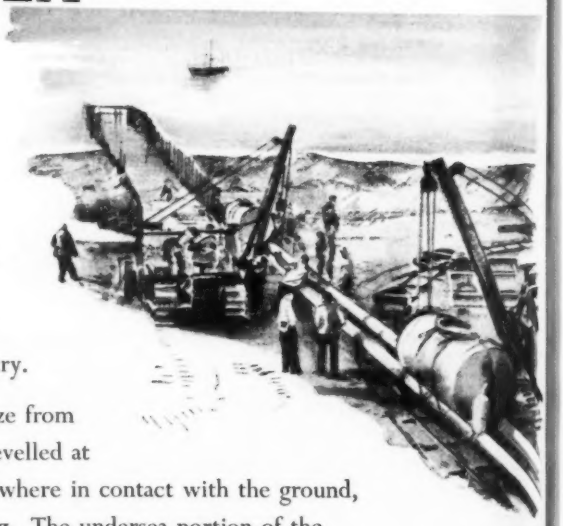
# UNDERGROUND AND UNDERSEA

*Pipelaying Contractors:*
*Taylor Woodrow Construction Ltd.*
*in association with*
*Collins Submarine Pipelines Ltd.,*
*also Constructors John Brown Ltd.*



Shown in the course of preparation for launching at Arish Mell, Dorset, is part of a pipeline for conveying atomic wastes from the Atomic Energy Establishment at Winfrith Heath into the English Channel.

It runs for five miles underground from Winfrith to the coast and then under the sea for a further two miles. For the underground portion, twin pipelines were laid, each consisting of a pipe within a pipe. The underwater outfall is believed to be the longest installed in this country.

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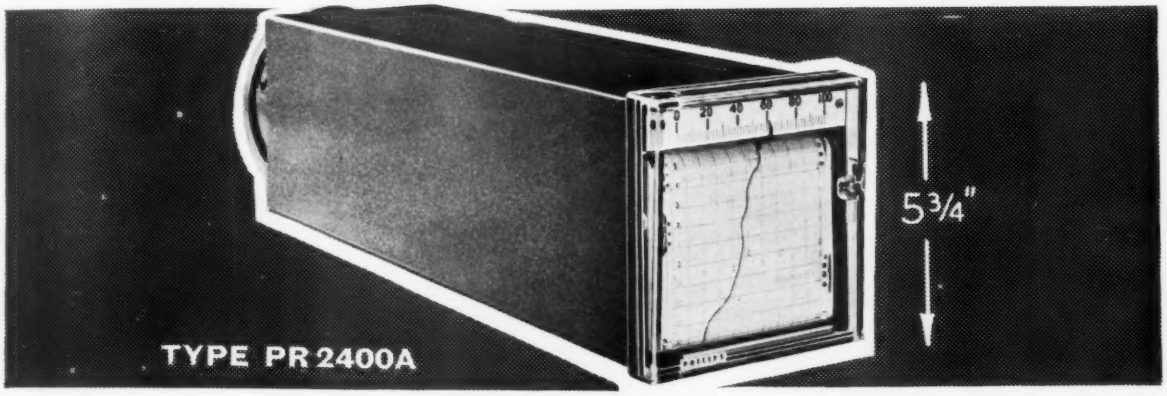
# MINIATURE RECORDER

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**RECORDING SECTION** Strip chart, width 100 mm, length approx. 9 m. The chart is wound into an exchangeable casette. Visible length of 100 mm. After opening the door the chart can be pulled out over a length of 80 cm. Chart returns automatically into the casette.

**CHART-SPEED** With built-in gear box 3 different speeds can be selected: 10, 20 and 60 mm/h. Can be supplied with electro-mechanical clutch so that by means of external switch, chart movement can be accelerated by a factor of 60.

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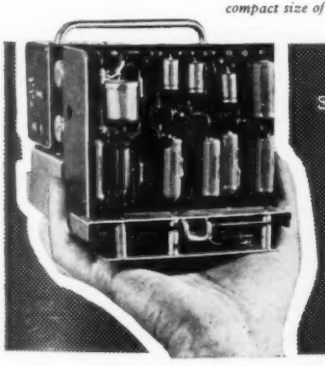
MINIMUM SPAN 5 mV · MAXIMUM SPAN 250 mV
ACCURACY 0·5%; the accuracy can be maintained after exchange of range box.
REPRODUCIBILITY 0·2% of span · SCALE LENGTH 100 mm.
STABILITY 10% mains variations have an influence of less than 0·1%
BALANCING SPEED Less than 1 sec. for full scale deflection; damping critically adjustable.

**RECORDING** With flexible capillary stylus supplied from sealed ink container mounted under measuring carriage. Line thickness approx. 0·3 mm.

**CONSTRUCTION** Sheet-metal case in grey hammertone with all plastic door. Front dimensions 144 x 144 mm; depth 510 mm; panel opening 138 x 138 mm. (5¾″ x 5¾″—20″—5½″ x 5½″).

PRODUCT OF PHILIPS, EINDHOVEN, HOLLAND



*This photograph shows the lighter weight and compact size of the plug-in transistorized amplifier.*

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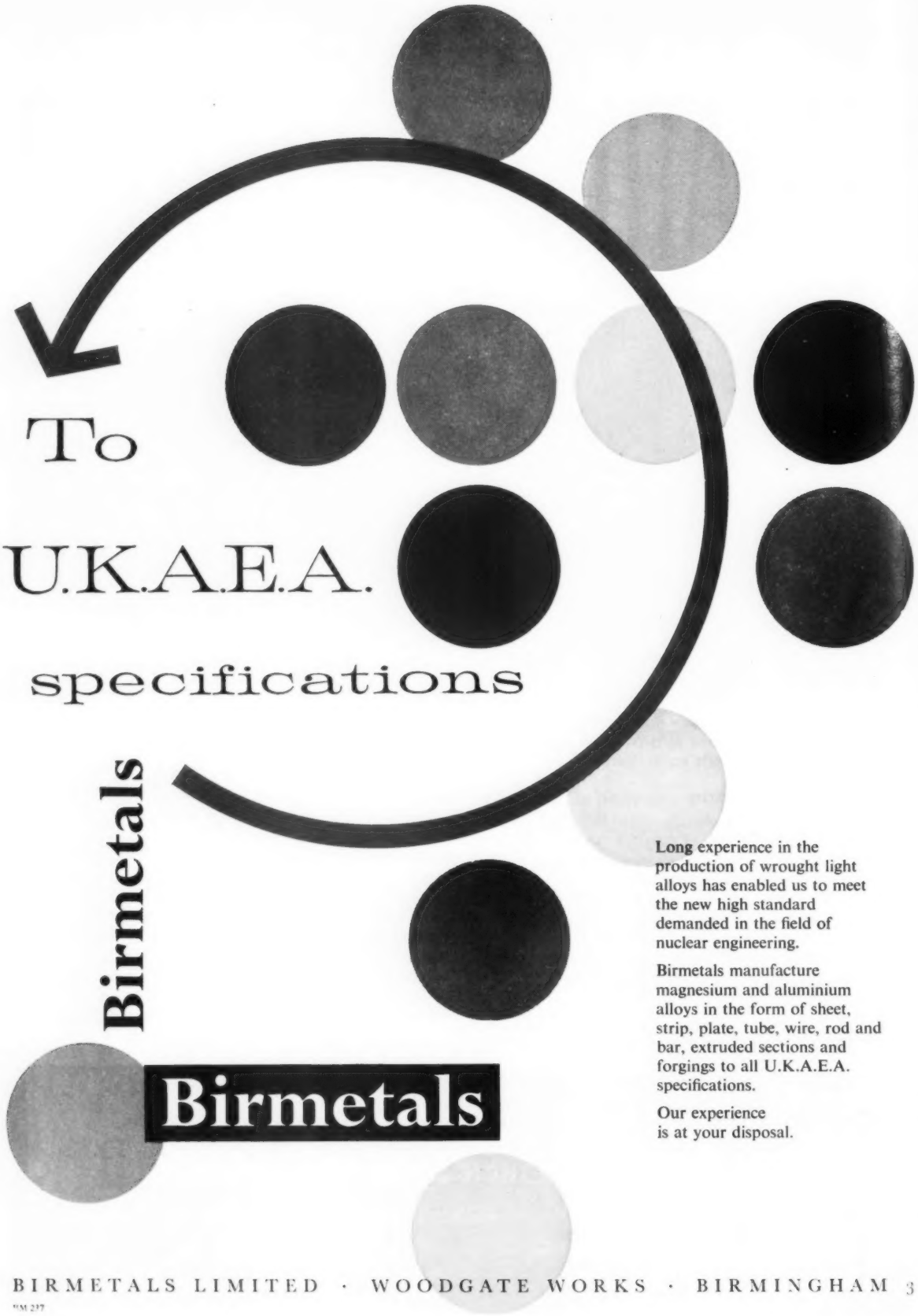


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TM 237

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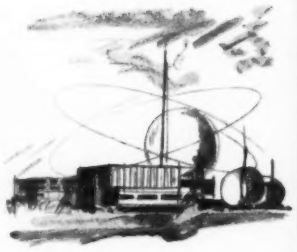
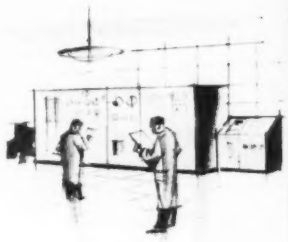
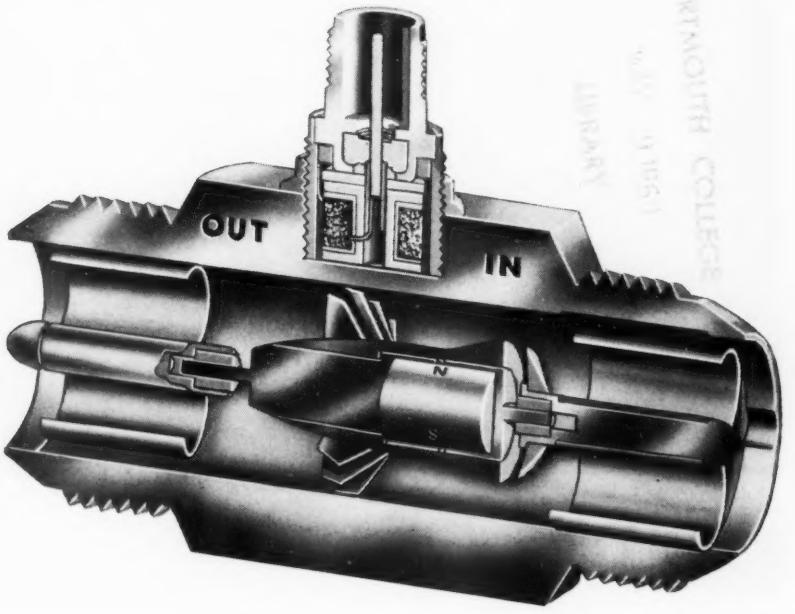
# the de Havilland POTTERMETER

## *sets new standards of accuracy and reliability*








This new turbine-type flowmeter enables major advances to be made in the techniques of flow measurement and control. The de Havilland Pottermeter is the only flowmeter which offers all these features:

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Models available to measure flows from 0·1 to 40,000 Imperial gallons per minute, at a wide range of operating pressures. Larger and smaller sizes made to order.

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*Olympia*
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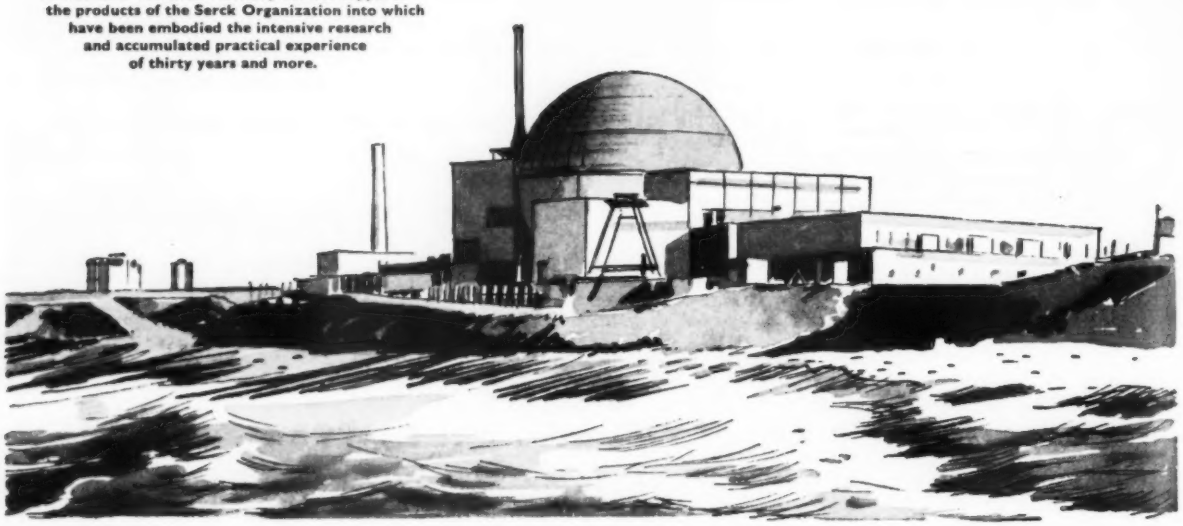

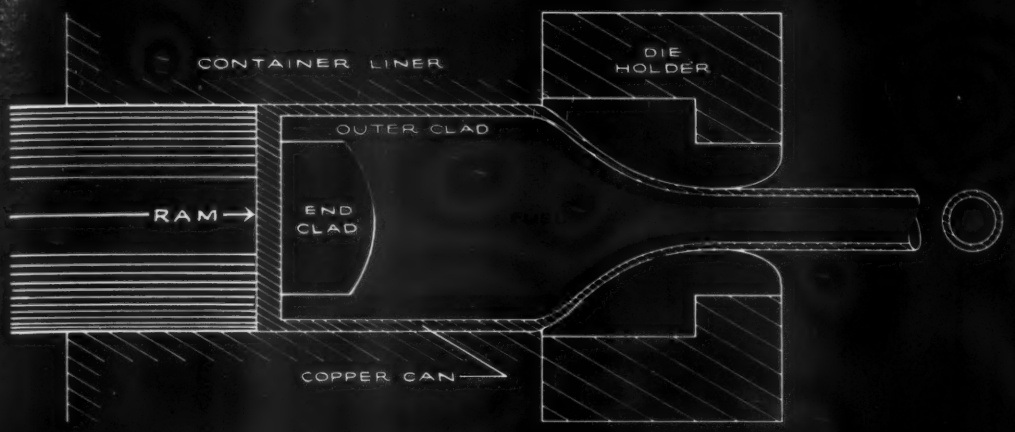


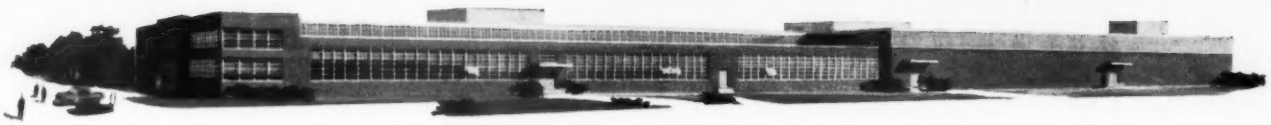

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We co-extrude tubular uranium aluminum elements of the CP-5 type; plate type cermet elements; alloy elements of uranium with zirconium, niobium and molybdenum as pins, tubes or rods. We can offer wire fuel elements up to 50 feet in length.

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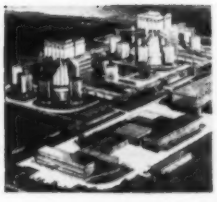

**BERKELEY**
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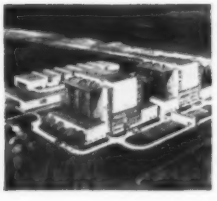

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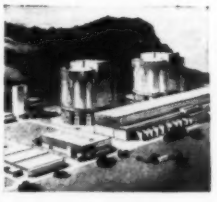
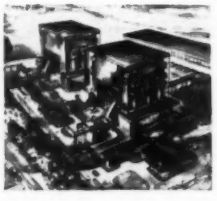


**HUNTERSTON**
**(G.E.C. — Simon Carves Group)**



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*(An impression by Mr. Basil Spence, Consultant Architect to Nuclear Civil Constructors, showing how the design blends into the landscape of Snowdonia)*

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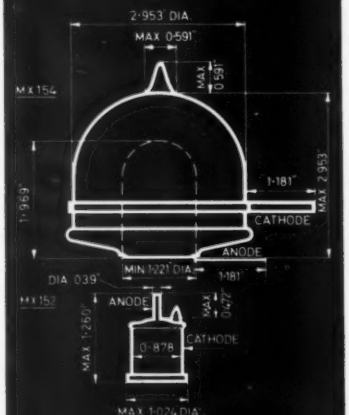


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8 CHANNEL RECTILINEAR RECORDER

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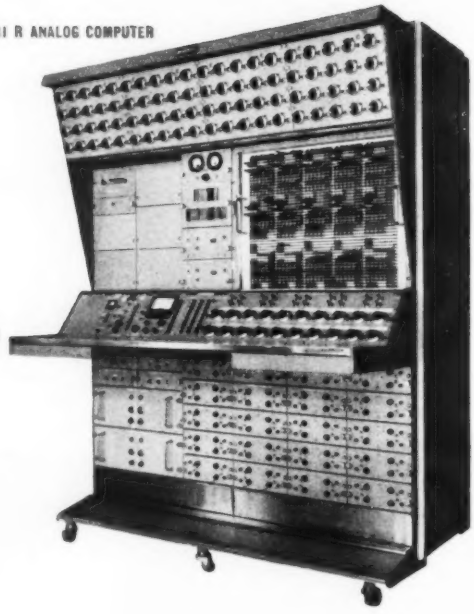

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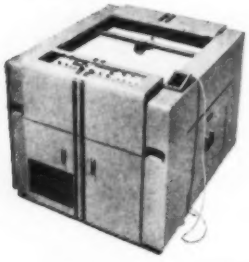
3033 B DATAPLOTTER



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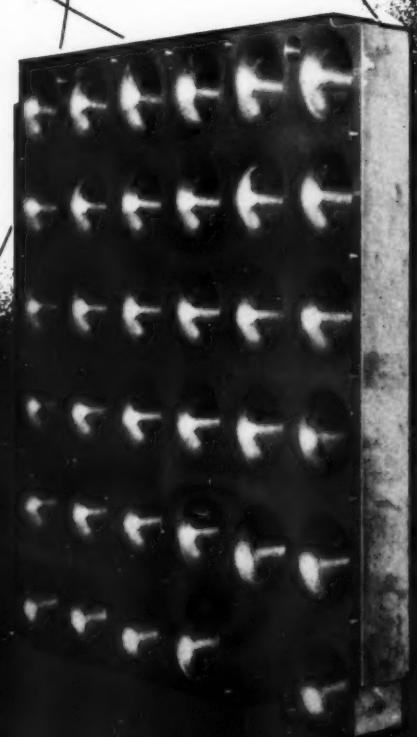
C E G B

THE CENTRAL ELECTRICITY GENERATING BOARD

# BEARMORE

## ...and nuclear power



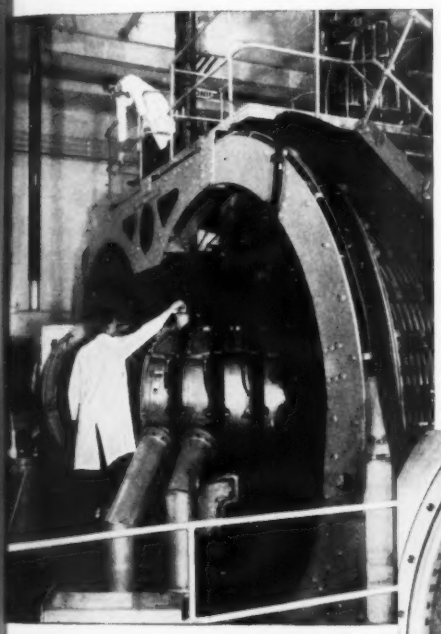
*Support Plates as supplied by*
*Atomic Power Stations.*

*tely equipped*

# TEDDINGTON BELLOWS
## and Nuclear Power
### HARWELL PAYS A TRIBUTE

Harwell top research scientists have freely acknowledged * that recent improvements in the operational efficiency of Zeta owe much to the introduction of a corrugated stainless steel liner inside the aluminium 'torus'. Having decided to use such a liner, they turned to Teddington engineers who, out of their experience in adapting their bellows expansion joints to various demands in a wide field of industry, produced exactly what was required for satisfactory running over long periods.

** In a paper read before the I.E.E. on 29/30 April 1959 by Mr. J. T. D. Mitchell of the U.K.A.E.A., Harwell*



In Zeta, experiments towards controlling fusion have resulted in gas temperatures of several million degrees centigrade being achieved for millisecond periods. View showing the torus.

This stainless steel liner has improved operational characteristics and requires less maintainance than the original aluminium liner system. Here is part of the twelve welded sections of Teddington stainless steel bellows tube of wall thickness 0·017″; it has 2½ convolutions per inch of a depth of 0·75″. The bellows is 38 inch bore and the whole toroidal bellows assembly has an axial length of 37 feet and an electrical resistance of 0·02 ohms.

**SEND FOR HANDBOOK R.53**

*Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.*

ZETA

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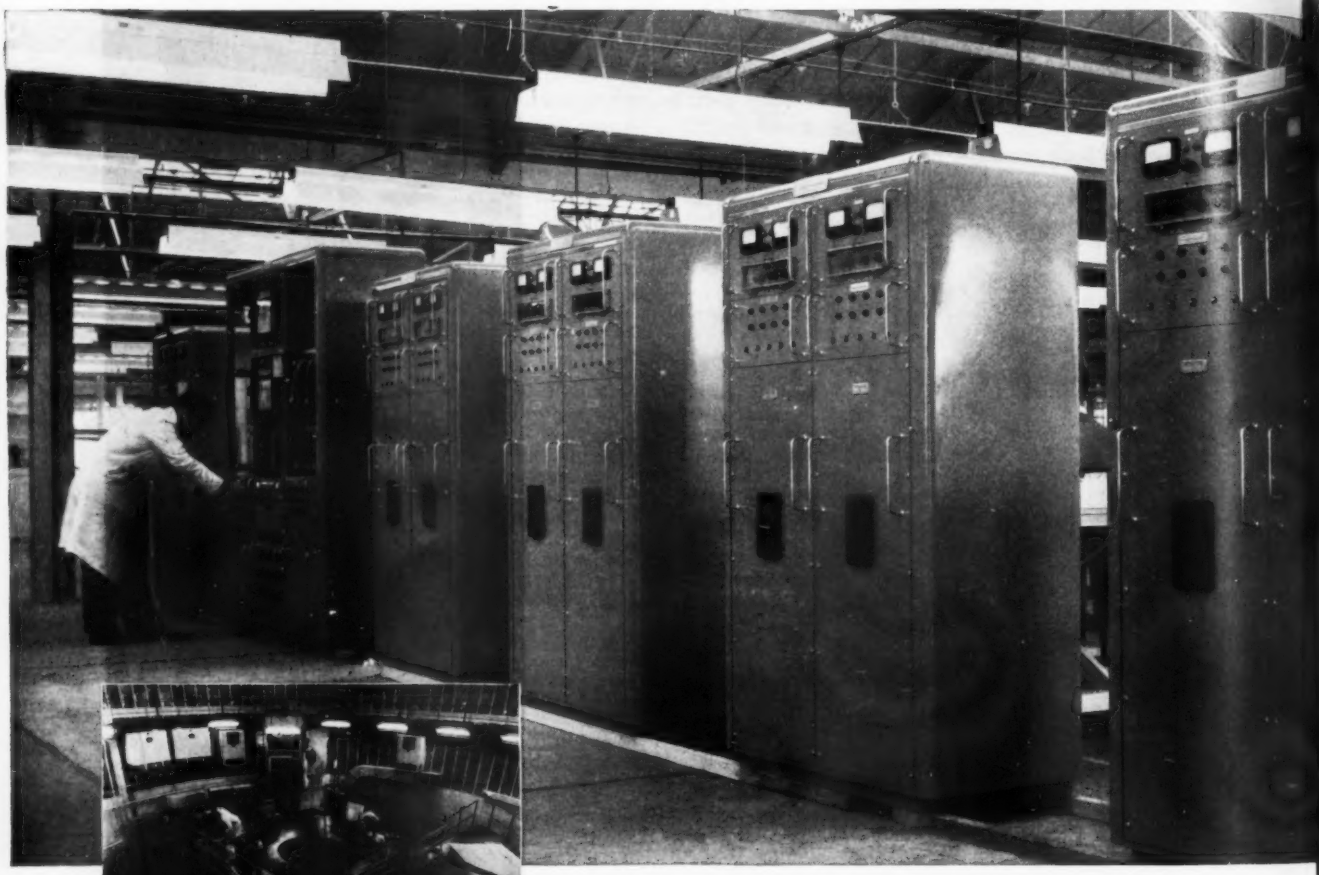
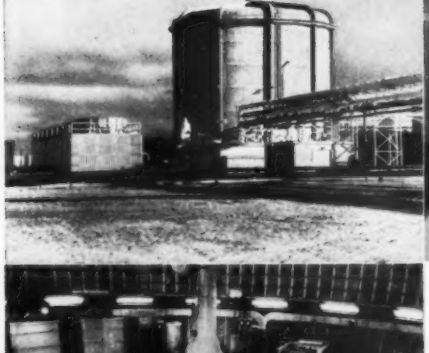
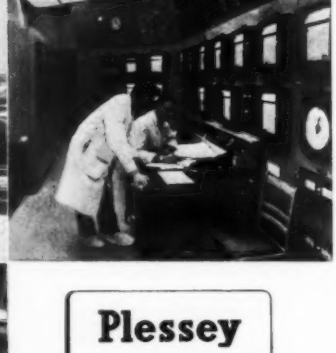
*PNL Burst Slug Detection equipment manufactured for the research reactor at Karlsruhe.*







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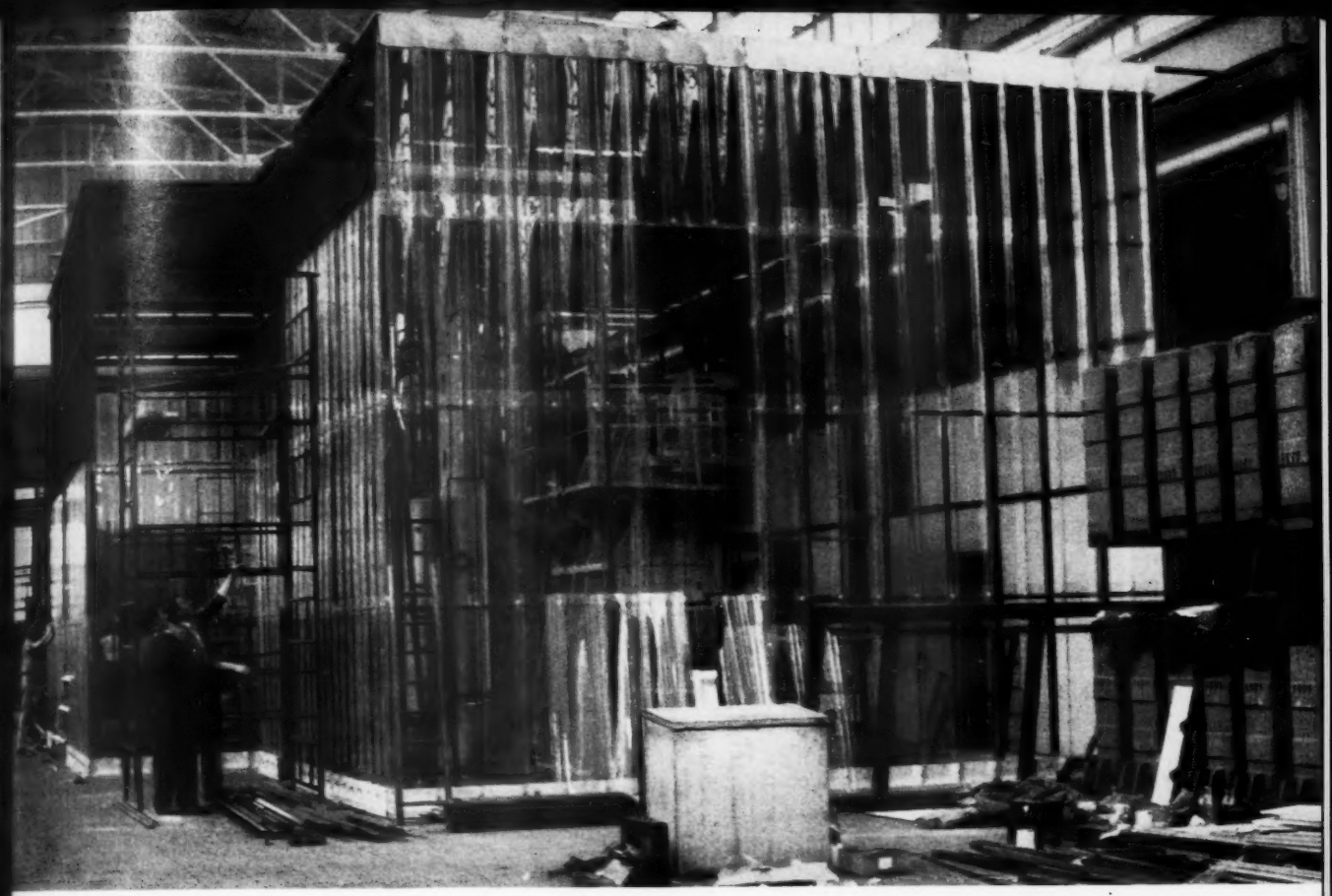

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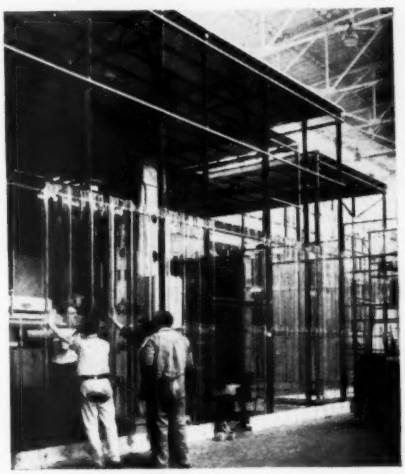

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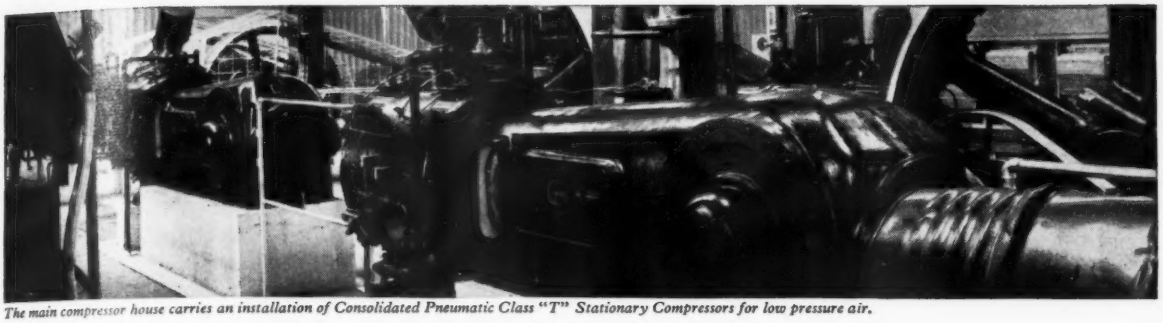

*The main compressor house carries an installation of Consolidated Pneumatic Class "T" Stationary Compressors for low pressure air.*

*At Hinkley Point Atomic Power Station*

# CP equipment is working hard for Taylor Woodrow...

*Difficult conditions for drilling, but all in a day's work to the Consolidated Pneumatic G-800 Tracdril, shown drilling 4" holes to 40-ft. in hard shale and limestone to clear a channel for the floating caisson.*

Wherever big construction projects are going on, CP air compressors and power tools will be found at work on the site. An example of this is to be seen at Hinkley Point Atomic Power Station being built for the Central Electricity Generating Board by The English Electric, Babcock & Wilcox, and Taylor Woodrow Atomic Power Construction Co. Ltd. The civil engineering contractors, Taylor Woodrow Construction Ltd. are using a big proportion of CP equipment for every type of duty, not only to save time and man-power but also to maintain their high standards. These pictures illustrate the complexity of operations being carried out at Hinkley Point. The excellent progress achieved by Taylor Woodrow reflects in some measure the efficiency of the CP equipment they have chosen for this work.

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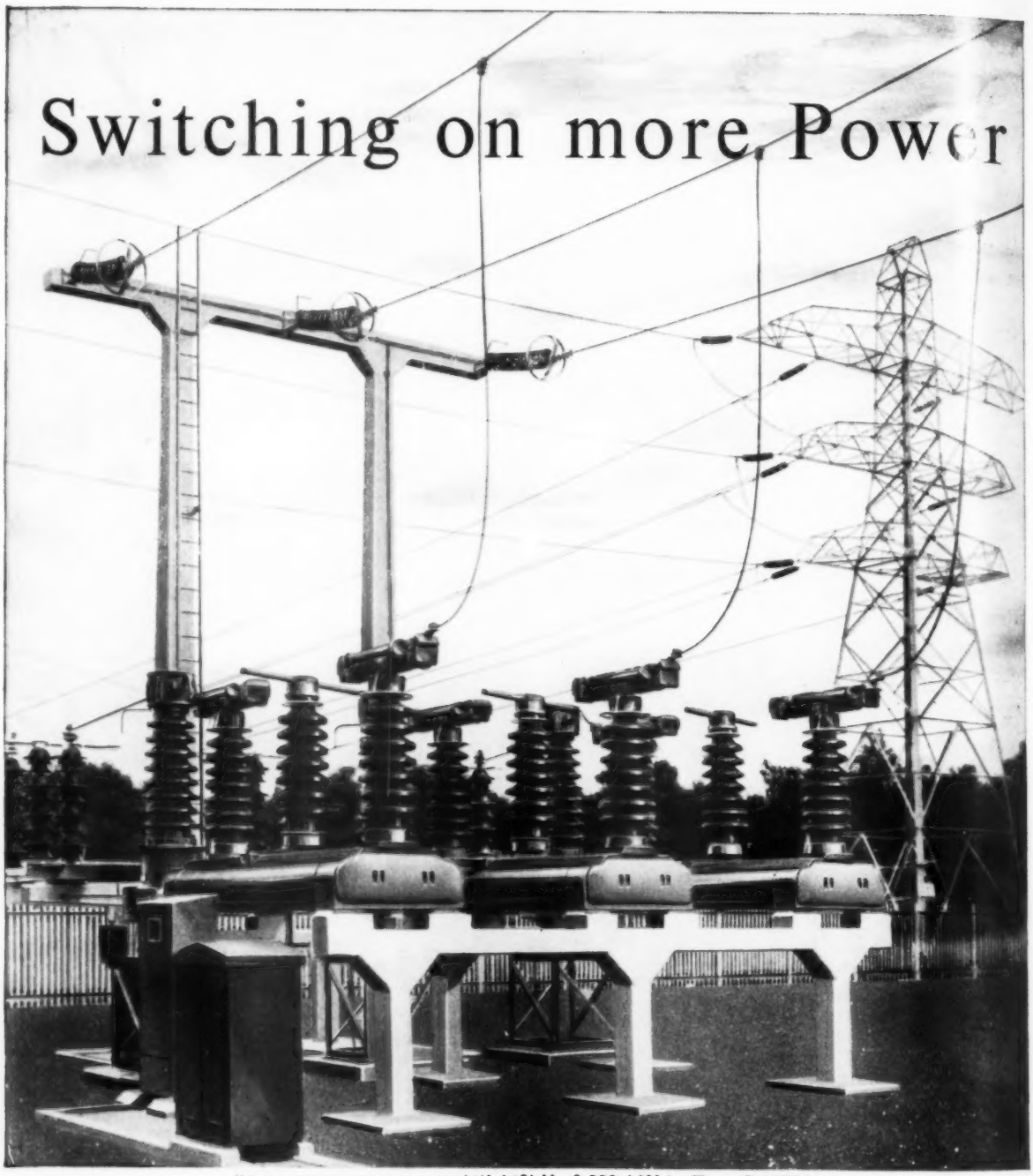

*The photograph shows an AEI 132kV., 3,500 MVA., Type GA6W4 Air-Blast Circuit Breaker installed in a British substation*

This type of breaker is in extensive use on the British grid system, and has been selected to control the output of Scotland's first Nuclear Power Station at Hunterston. Overseas, 132kV., 5000-MVA., Type GA6W4 breakers will be installed in seven new sub-stations in the Greater Buenos Aires area of Argentina.

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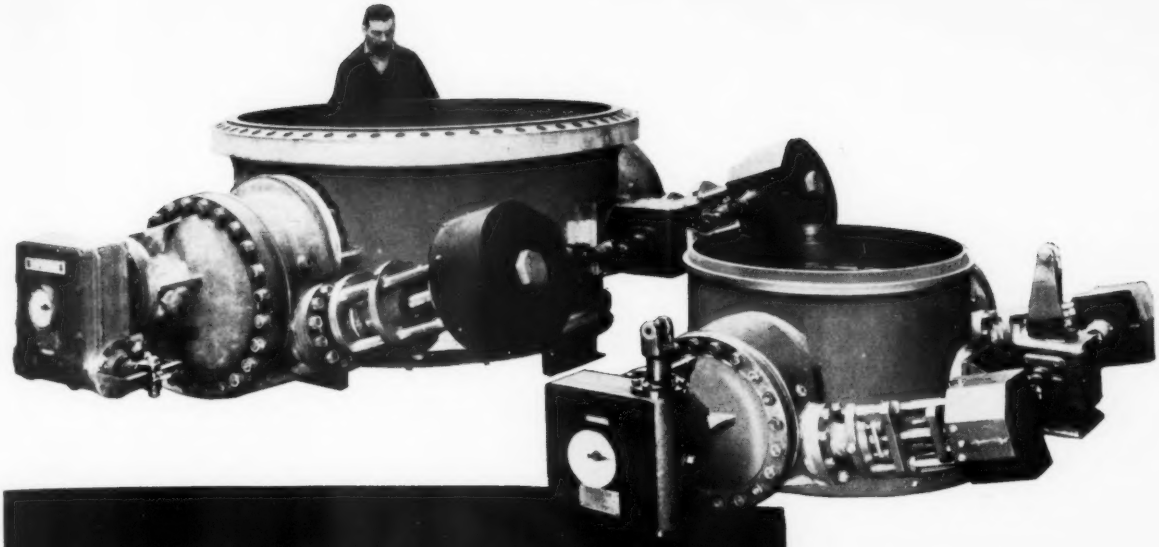
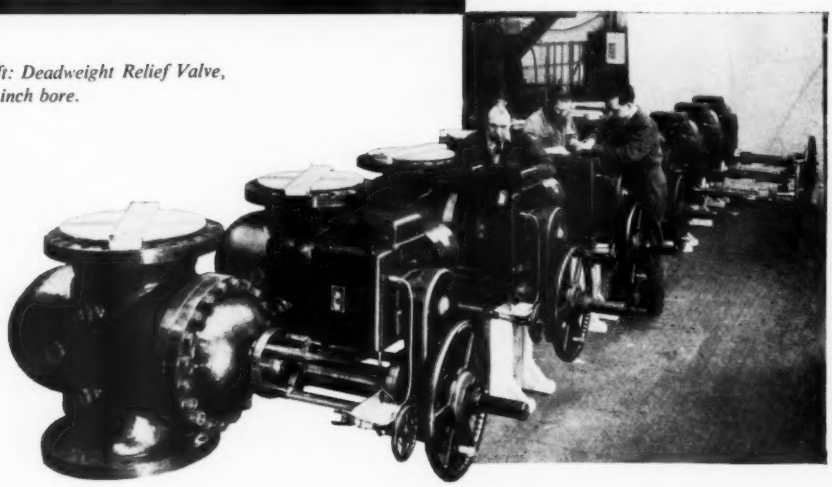


# HOPKINSONS' VALVES FOR NUCLEAR POWER STATIONS

*Above: "Tansphere" Valves for isolating $CO_2$ gas between reactor and steam generating plant. Supplied or on order for Bradwell, Hinkley Point, Latina and Trawsfynydd (Valves illustrated are 60 inch and 36 inch bore).*

*Below: Group of 24 inch electrically-controlled Hopkinson-Ferranti valves for a nuclear power station.*

*Left: Deadweight Relief Valve, 20 inch bore.*



Specialised valves (some of which are illustrated) needed in nuclear power stations are naturally entrusted to Hopkinsons because of their vast experience in the manufacture of valves for exacting duties. But, additionally, Hopkinsons are supplying large numbers of their electrically controlled valves, desuperheating equipment, combined stop and isolating valves, automatic exhaust valves, steam traps and all types and sizes of stop valves.

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HV121



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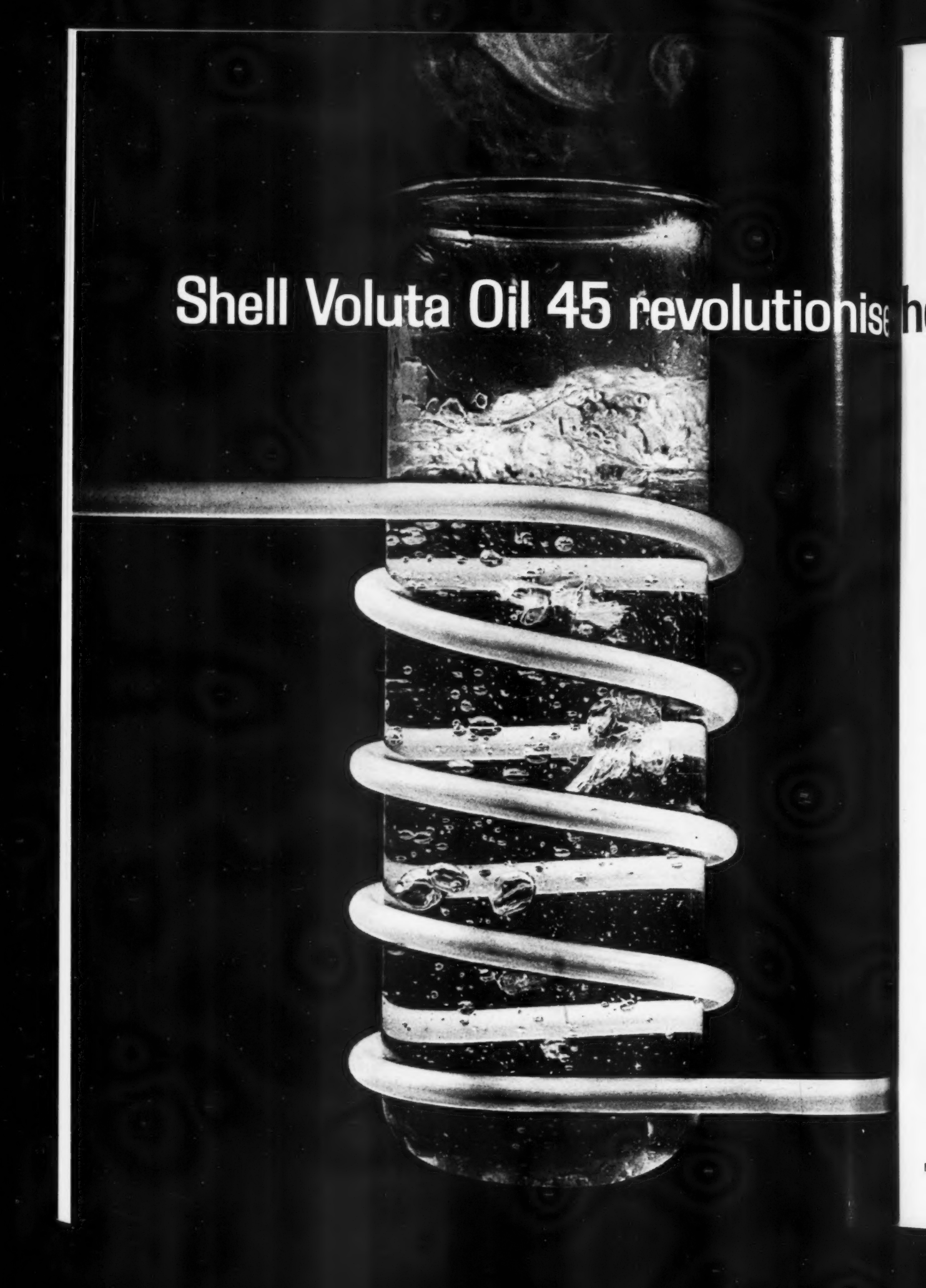

Shell Voluta Oil 45 revolutionise

# heat exchange practice

Before Shell produced Voluta Oil 45 it was thought that oils which were to be used for heat exchange purposes must have a high flashpoint —to reduce fire risk, and a high viscosity—to prevent excessive leakage through pump glands and to provide adequate lubrication for pump bearings at high temperatures. Heat exchange systems containing these viscous oils, however, were sluggish, particularly when started up from cold. The oil circulated slowly over the source of heat and suffered thermal decomposition, or "cracking". This, in turn, produced low flashpoint materials and carbon which insulated the heating surface.

Shell, therefore, began investigating the suitability of oils of lower viscosity and different chemical constitution. From this research was developed Shell Voluta 45.

Shell Voluta 45 contains hydrocarbons with a saturated ring structure which does not have the tendency that high viscosity straight chain paraffin hydrocarbons had—to break down at high temperatures. Because of its low viscosity Shell Voluta 45 heats up more quickly from cold and circulates more rapidly thus avoiding local overheating and thermal decomposition.

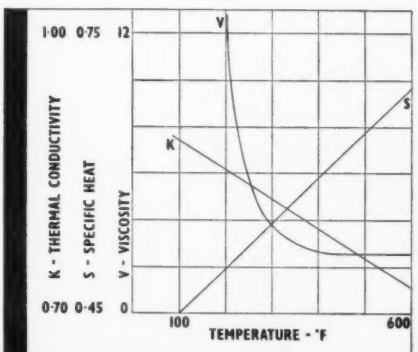
Shell Voluta Oil 45 has excellent heat transfer properties, good thermal stability and good lubricating properties. It is recommended for use in all closed heat transfer systems.

The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

## The Research Story

Laboratory research to compare the high temperature performance of various oils in a rig simulating practical conditions showed that when oils of varying viscosities were maintained at an average temperature of 325°C. for 200 hours, the closed flashpoint of the high viscosity oils had dropped to a lower figure than that of oils of lower viscosity, indicating that some thermal decomposition had taken place.

Experimental oils were subjected to Heat Stability Tests and to tests designed to measure the variation in heat transfer coefficient with time. The most promising of these oils was then given extensive field trials, both in Shell Installations and in industry. From this extensive research was developed Shell Voluta 45.




**Physical properties of Shell Voluta Oil 45.**
*K. Thermal Conductivity—B.T.U./sq. ft. per hour per 1°F. per inch.*
*S. Specific Heat—B.T.U. per lb. per 1°F.*
*V. Viscosity—Kinematic centistokes.*

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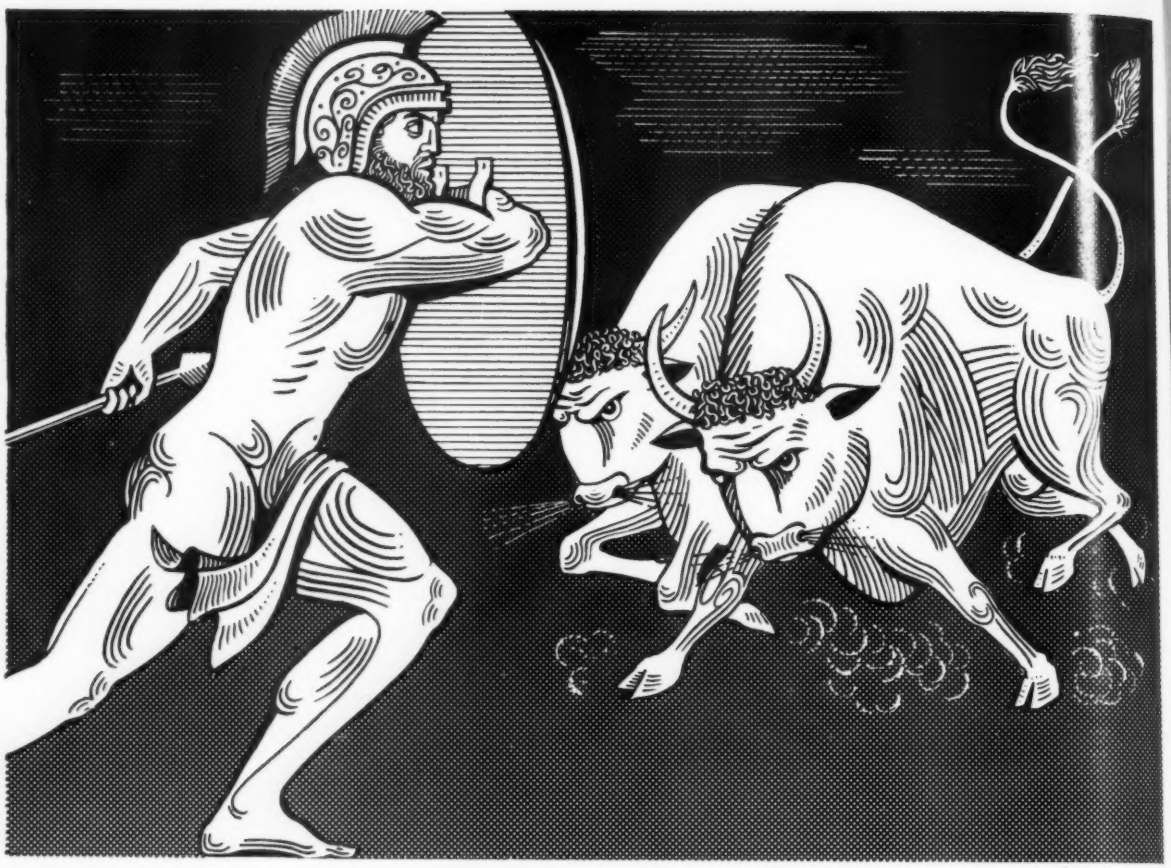
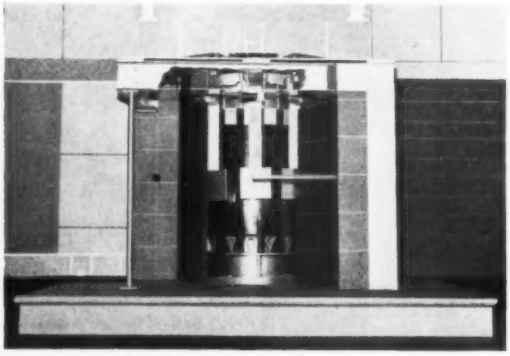


# THE TASKS OF JASON

*Among the formidable tasks performed by the Greek hero Jason, in his quest for the Golden Fleece, was the taming of the fierce bulls of King Aeetes. Jason was undaunted by their ferocity, their snorts of fire and smoke, their thundering hooves of brass; and, by the skilful use of his spear and shield, he was able to arrest and control their terrible relentless charges.*



In this nuclear age man's arrest and control of great energy is symbolised in achievements such as the new 'Jason' experimental reactor designed and built by the *Hawker Siddeley Nuclear Power Company* at Slough. And here once again General Radiological instrumentation is performing a vital job. For the Argonaut experimental reactor being built in Milan, the Agip Nuclear engineers have specified General Radiological instrumentation. For the latest 'Jason' shortly to be exported to Holland, the Hawker Siddeley engineers have chosen General Radiological instrumentation. Like 'Jason's' spear and shield it is the instrumentation system which is the means of achieving the reliable and precise control of energy in a reactor.

*General Radiological's instrumentation is now specified for the major nuclear power stations at Bradwell, Berkley, Hinkley Point, Hunterston and at Latina, near Rome.*

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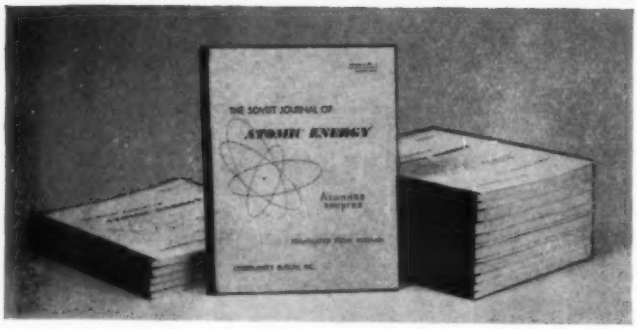


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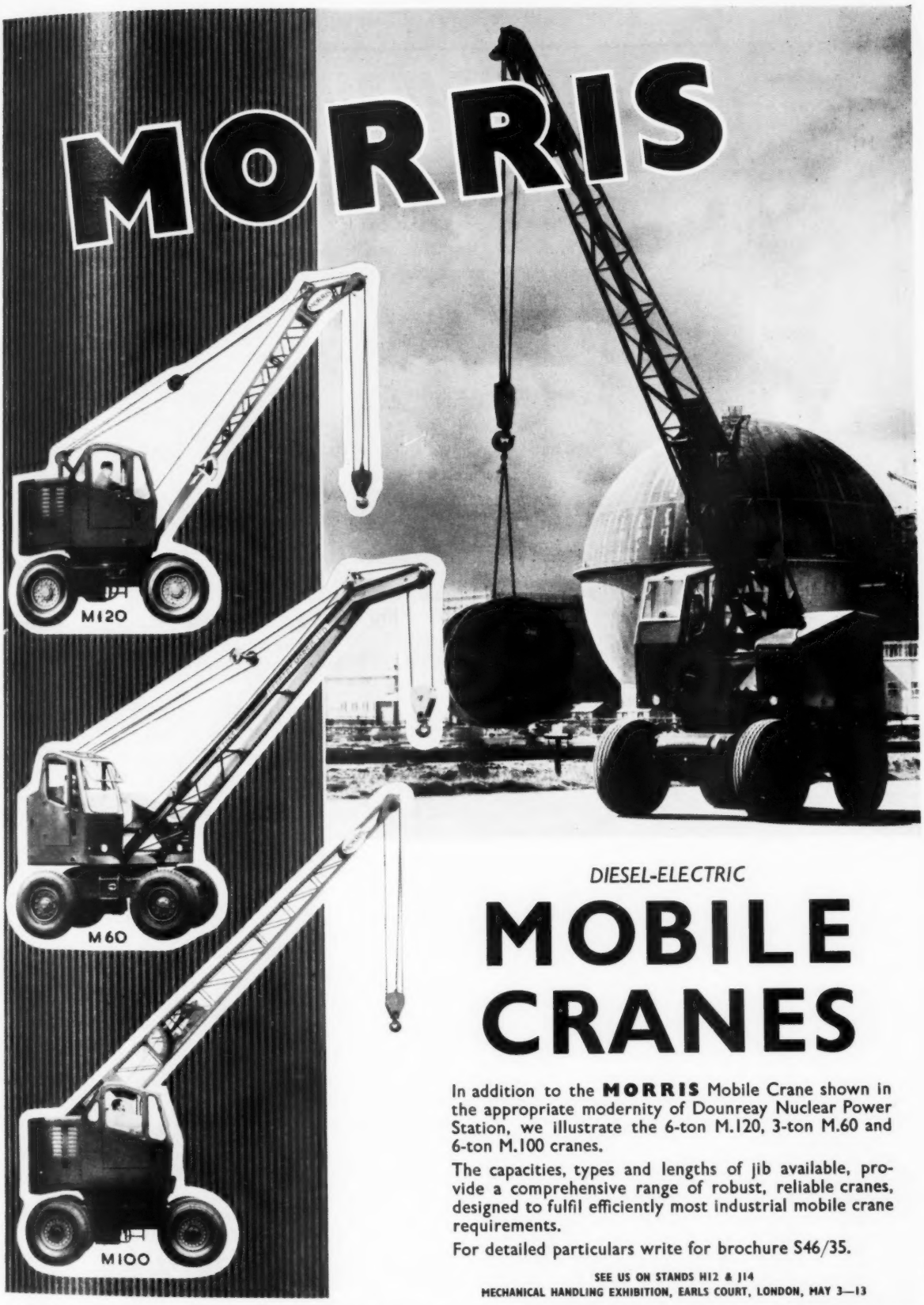


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**NEWTHERM Calcium Silicate insulation manufactured solely by NEWALLS is the most versatile material you can use for application up to 1400°F. Try it. Put a sample section or slab on part of your plant and *prove for yourself* its outstanding ability to withstand impact and water damage.**

## LIGHTNESS

Weight - for - weight, NEWTHERM compares favourably with many materials far inferior in thermal efficiency and strength. This light weight is evidenced in the handleability of NEWTHERM, which even in the largest sections can easily be carried in one hand.

## MOISTURE RESISTANCE

You can immerse NEWTHERM in water and its strength remains largely unimpaired. Nor does it become deformed when in contact with moisture, thus work-in-progress need not be covered. Wherever damp or humid conditions pertain, NEWTHERM is the logical material to use.

## STRENGTH

Of major advantage on remote sites, NEWTHERM is unusually strong and rigid, and can withstand rough handling in transit and erection. In the case of vulnerable large-diameter sections, the hard surface offers excellent protection.

## EASY APPLICATION

Supplied in pre-formed sections and slabs, NEWTHERM is available in a wide range of standard sizes (and also as plastic). The smooth surface and straight edges permit easy and speedy fitting, with minimum joints and neat finish.

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*Agents and Vendors in most markets abroad.*

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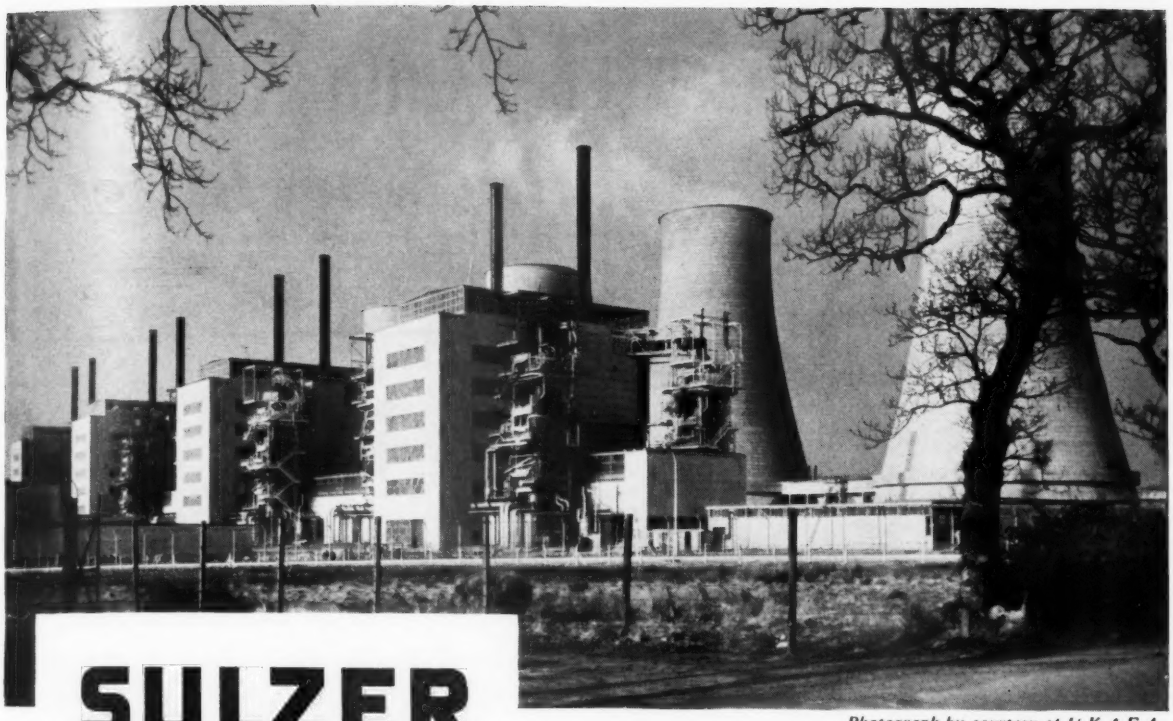
# NEWTHERM calcium silicate insulation

*Please ask for your copy of the NEWTHERM booklet. Packed with information on limiting temperatures, thermal conductivity, compressive strength, applicational details, etc., it's a must for your bookshelf. Copies available from sole manufacturers—NEWALLS*



*Photograph by courtesy of U.K.A.E.A*

# SULZER

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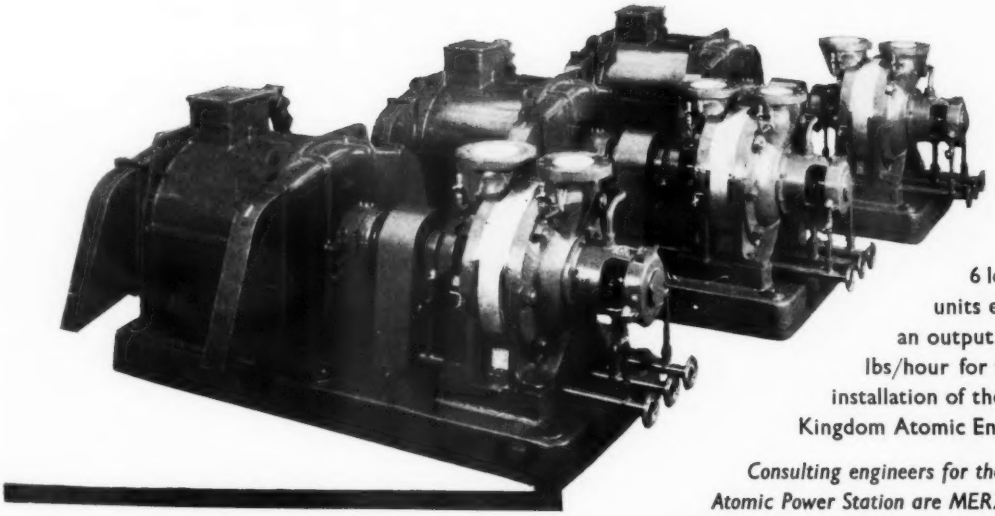

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*Consulting engineers for the Chapelcross Atomic Power Station are MERZ & McLELLAN. Civil engineering contractors are the MITCHELL CONSTRUCTION CO., LTD.*

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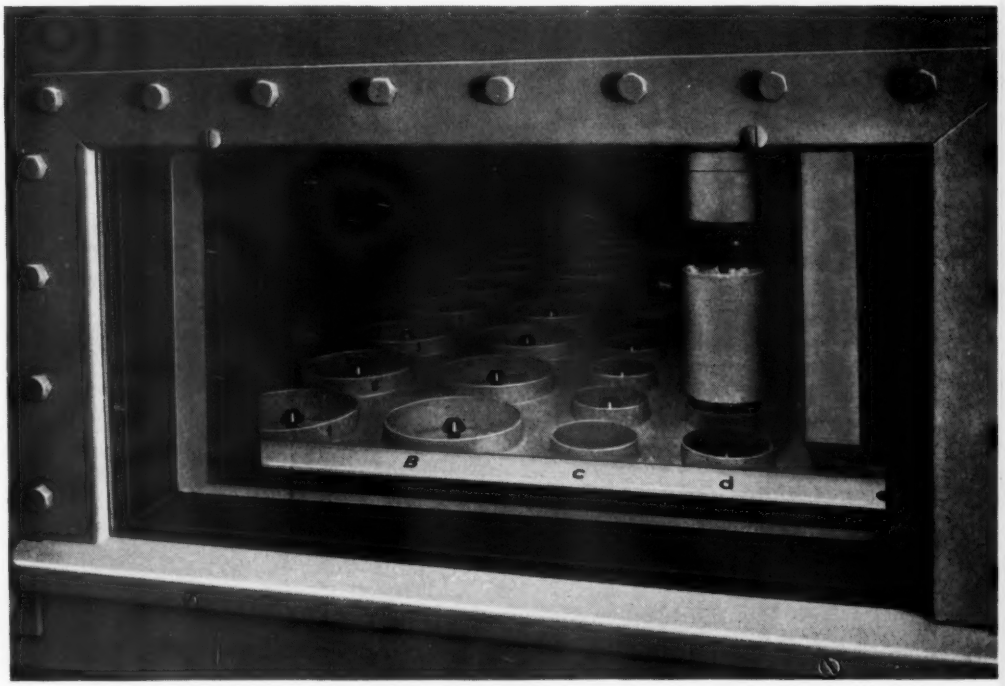


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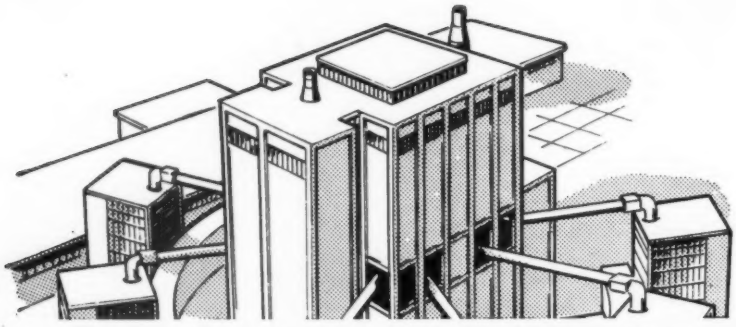

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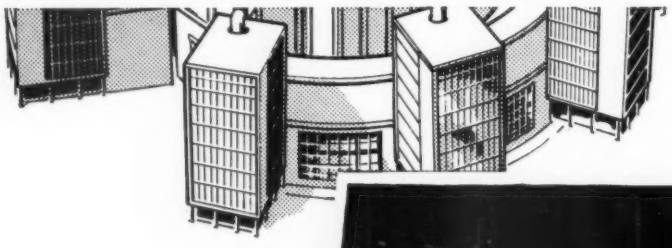

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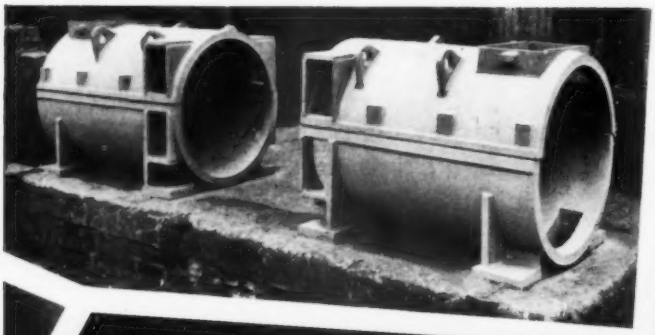

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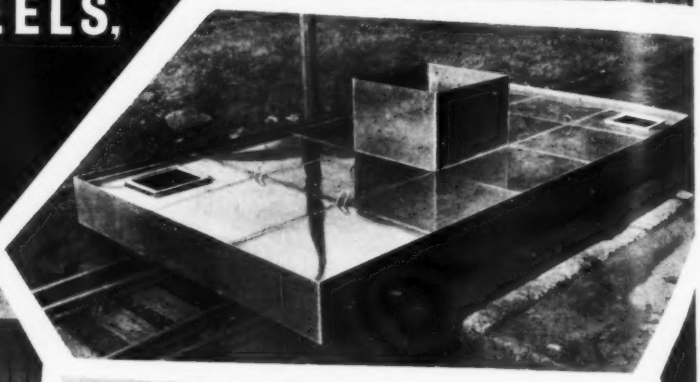

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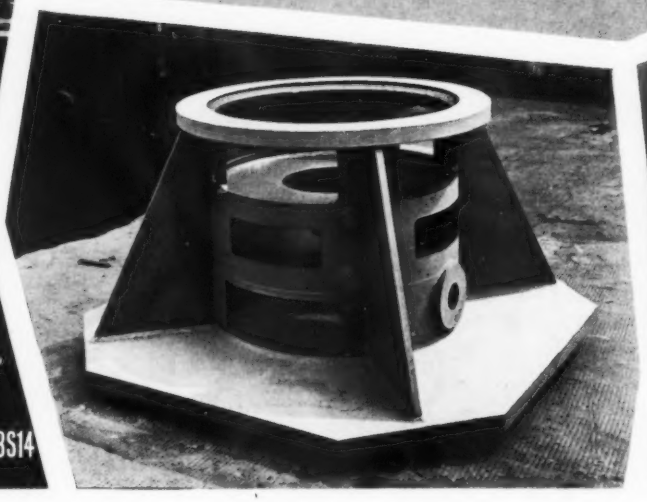

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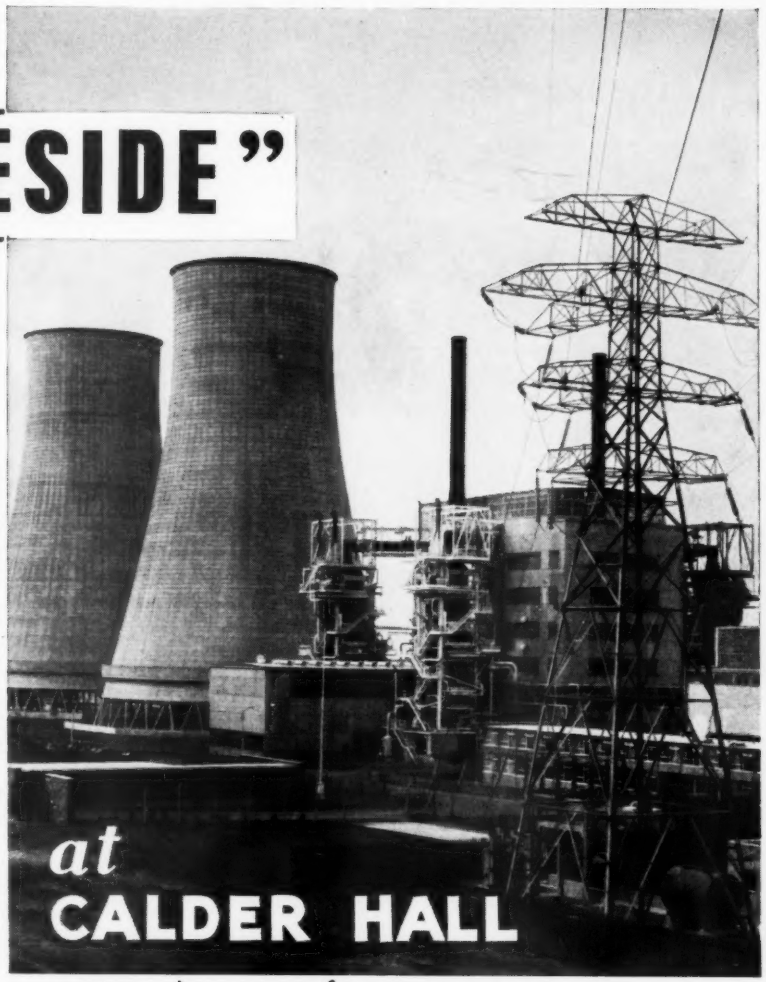


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With the advancement of Atomic Power, cables must play an important part in the efficiency and reliability in the production of Nuclear Energy. Only the best is good enough and Wandleside Cables are eminently suitable.

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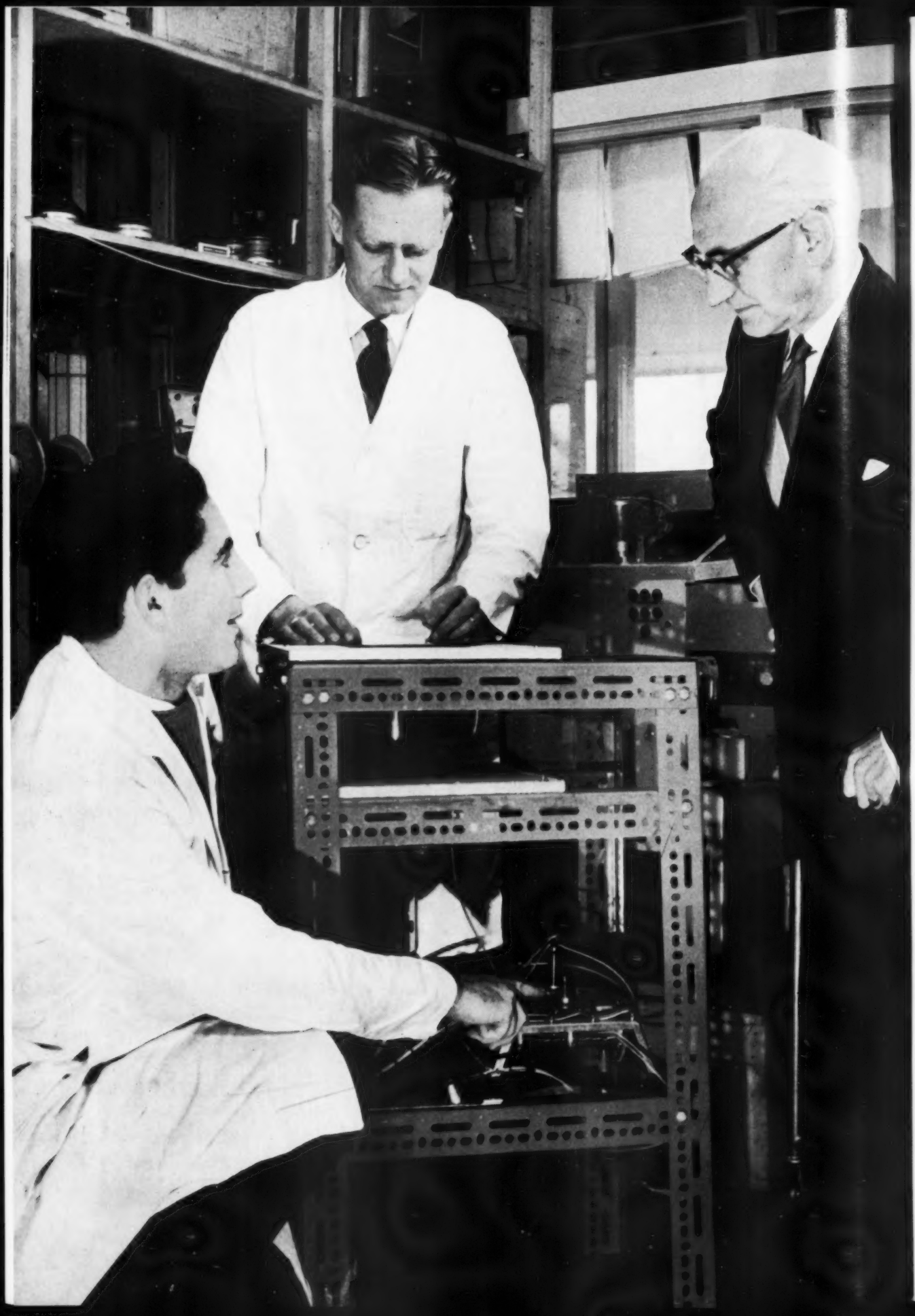

# That's to take rolling motion transient response into account, of course, sir . . .

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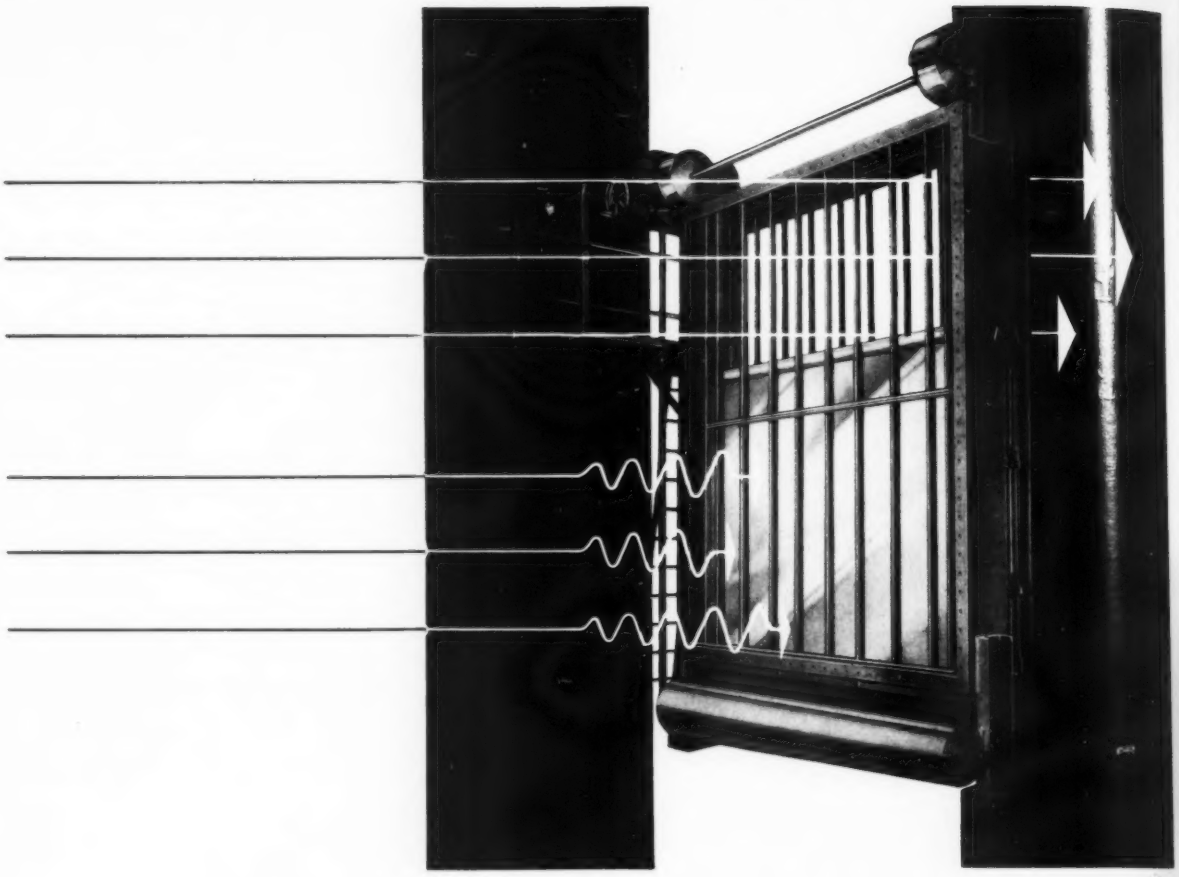

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AT LONG LAST . . . A Damper to meet with the conditions in Boiler and Power Station Flues and yet require the minimum of maintenance. The well known difficulties of traditional arrangement are overcome with the Dowling Damper which provides an economical and reliable seal between flue sections of all sizes. It is designed and constructed to withstand varying conditions of temperature, gas pressure, acids and dust that are prevalent in Boiler and Power Station Flues. It can be hand operated or power driven and supplied with air-operated seals if required.

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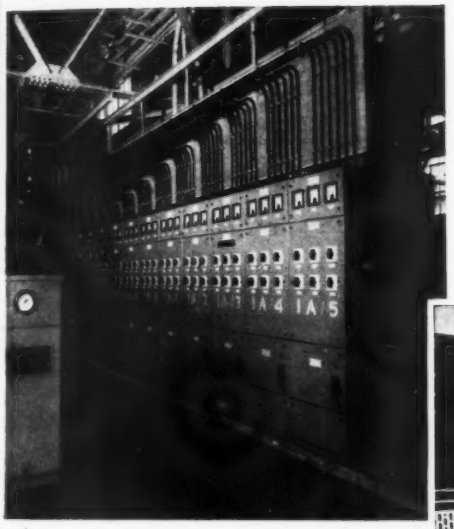
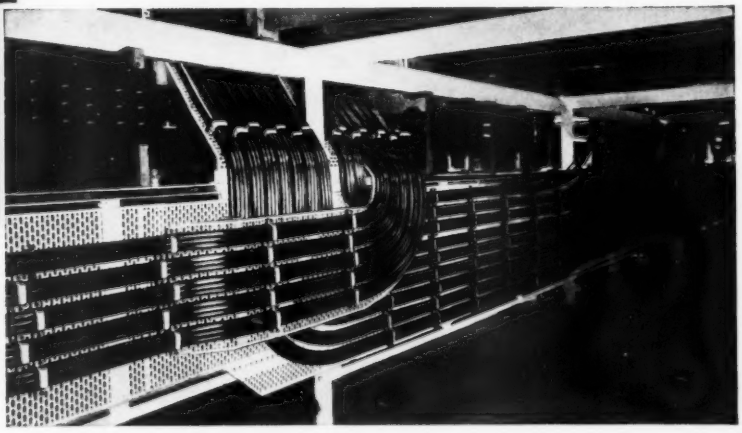
## *serves the Atomic Age....*



Men are working on the lonely coasts of Britain, and vast and unfamiliar structures are rising to provide the Nation's new electrical power sources.

This is visible progress. Yet, in the changing scene there are constants. Pyrotenax M.I.C.C. Cables, for instance, have been the consistent choice of electricity supply authorities for years. Twenty years ago the most "modern" power stations installed "Pyrotenax"—and the same original cabling still serves today. Little wonder that in this present age too, "Pyrotenax" is being specified for the lighting and power services in the various automic plants of the United Kingdom Atomic Energy Authority. Current *generating* may change, but current *carrying* is always best left to "Pyrotenax"!

*Main control switchboard at one of the United Kingdom Atomic Energy Authority Research Establishments showing Pyrotenax cables feeding lighting, power and instrument circuits.*



*Power and instrument cabling at the rear of the main switchboard. (Contractor N. G. Bailey Limited Leeds.)*

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**Pyrotenax**

m.i. COPPER COVERED CABLE

*The use of the trade name 'Pyrotenax' is exclusive to the products of this Company and its associates.*

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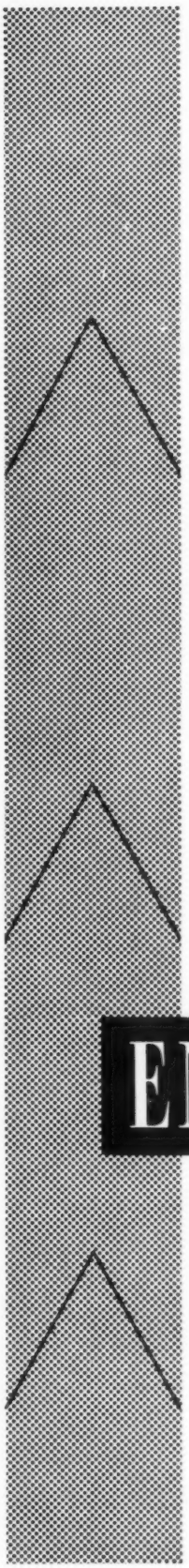

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*Photograph by courtesy of A.E.I. Ltd., Turbine-Generator Division, Rugby.*

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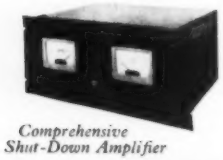

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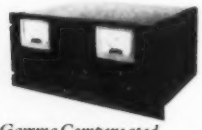

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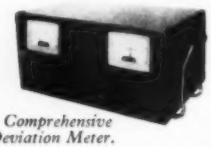
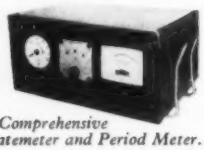


*Comprehensive Deviation Meter.*



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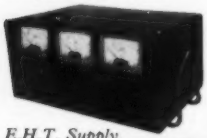
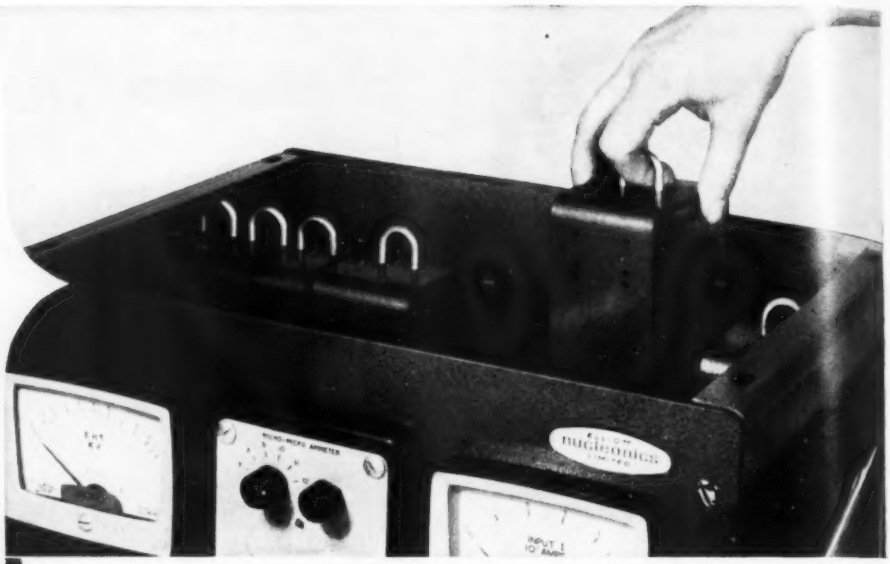


*E.H.T. Supply.*



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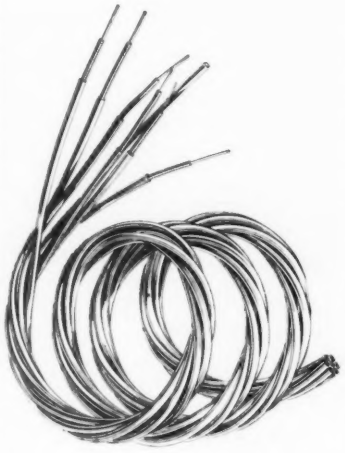

A flexible duct for instrument control which consists of a number of small diameter seamless stainless tubes interwoven to form a single cable and then helically coiled to obtain flexibility. One of the tubes is left open to carry gas and the rest contain insulated wire for the electrical circuits.

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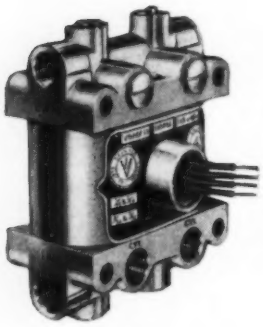

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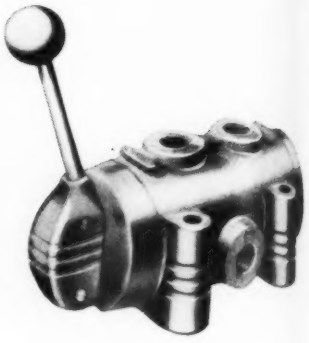
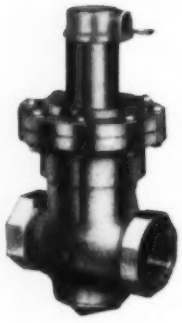


**Lever operated 4-way valve for manually operated directional control.**



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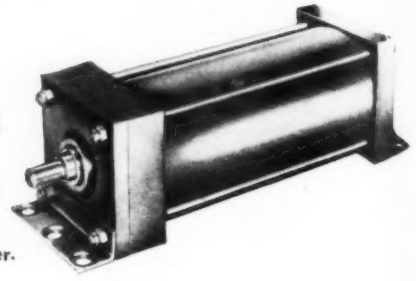
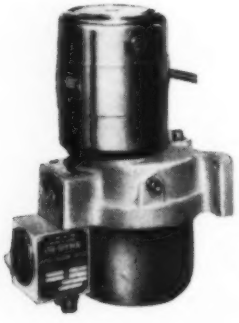
Covers a wide field of valves and cylinders for all applications. Also included is a range of air operated rotary indexing tables.



**10" diameter pneumatic cylinder.**



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Complete packaged hydraulic power units comprising motorised pump, reservoir and valve gear. Pressures range to 3000 p.s.i. with a displacement of 2 g.p.m.

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THIS RANGE OF EQUIPMENT, THE MOST COMPREHENSIVE IN THE WORLD, IS AVAILABLE THROUGH BRITISH ARCA REGULATORS LIMITED, TOGETHER WITH THEIR OWN ESTABLISHED RANGE OF CONTROL EQUIPMENT.

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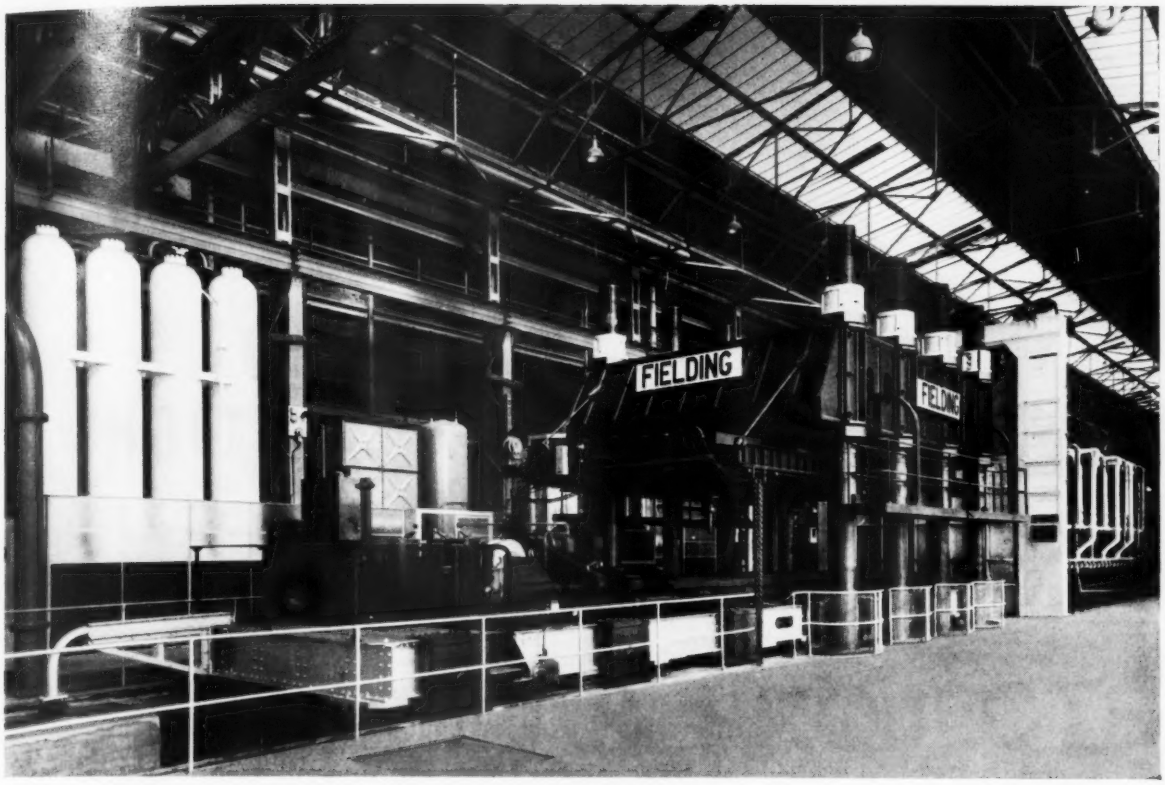
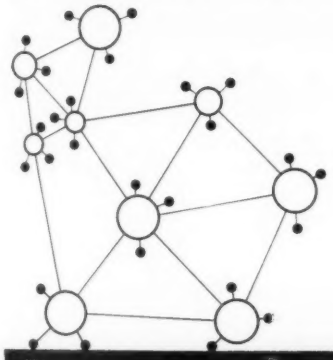



**This press has been supplied to the Whessoe Company of Darlington for the shaping of the heavy steel plates required for the shells of the large reactor pressure vessels of nuclear power installations.**



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'FIELDING' 4,500 tons, multi-ram, upstroking plate press, designed to carry out the shaping of heavy steel plates. The press will accept the largest plates that are being manufactured by the British Steel Industry today; with a substantial margin for future development. The pit in which the press is housed is 31ft. in depth and the weight supported by the foundation is 780 tons. Hydraulic power for press operation is supplied from high and low pressure 'FIELDING' accumulator systems, the high pressure circuit being powered by 'FIELDING' H.3. type three throw pumps.

# 4,500 tons Multi-ram Upstroking Plate Press

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# 2 IMPORTANT DEMINERALISATION PLANTS

**William Boby & Co. Ltd. have been entrusted with the execution of the demineralisation water treatment plants at :**

## 1 CHEMSTRAND LTD., N. Ireland

*(Main Contractors : Messrs. Constructors John Brown)*

For their new 'ACRILAN' factory at Coleraine, N. Ireland, Messrs. Chemstrand have installed a 10,000 galls./hr. 'Boby' demineralisation plant for process and boiler feed water.

*The plant comprises the following sections :*

Coagulation and Settlement — Filtration — Cation Exchange — Weakly basic Anion Exchange — Degassing — Mixed Bed Ion Exchange.

## 2 VEITSILUOTO O/Y, Finland

The Veitsiluoto paper mills of Finland have installed a 13,400 galls/hr. 'Boby' demineralisation water treatment plant for feed water for boiler working at 1,750 p.s.i.

*The plant comprises the following sections :*

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**Established in 1875**

## WILLIAM BOBY & CO. LTD.

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**Ambient pressures in which these circulators work range from normal atmospheric to 300 p.s.i. at temperatures up to 350° C . . . and the gases involved are carbon dioxide, nitrogen and helium. Pressure rises through circulators extend up to 30 p.s.i. and flows through units cover a range up to 8000 lb/hour.**

**Circulators are usually of the high speed motor driven type with specially designed radial impellers, motors being gas and liquid cooled.**

**Zero leakage is an important feature of these designs.**

PLANNAIR specialists in air movement

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# CORROSION

Many thousands of tons of steel are lost through corrosion every year and much of this can be saved. *There is a remedy.*
"Superlative" Metal Primer provides a positive protection against corrosion for all ferrous metals. It is quicker and easier to apply than conventional Lead Coatings and is infinitely cheaper. But, as *efficiency* is the factor that matters, and "Superlative" is so economical and so effective, it pays to specify

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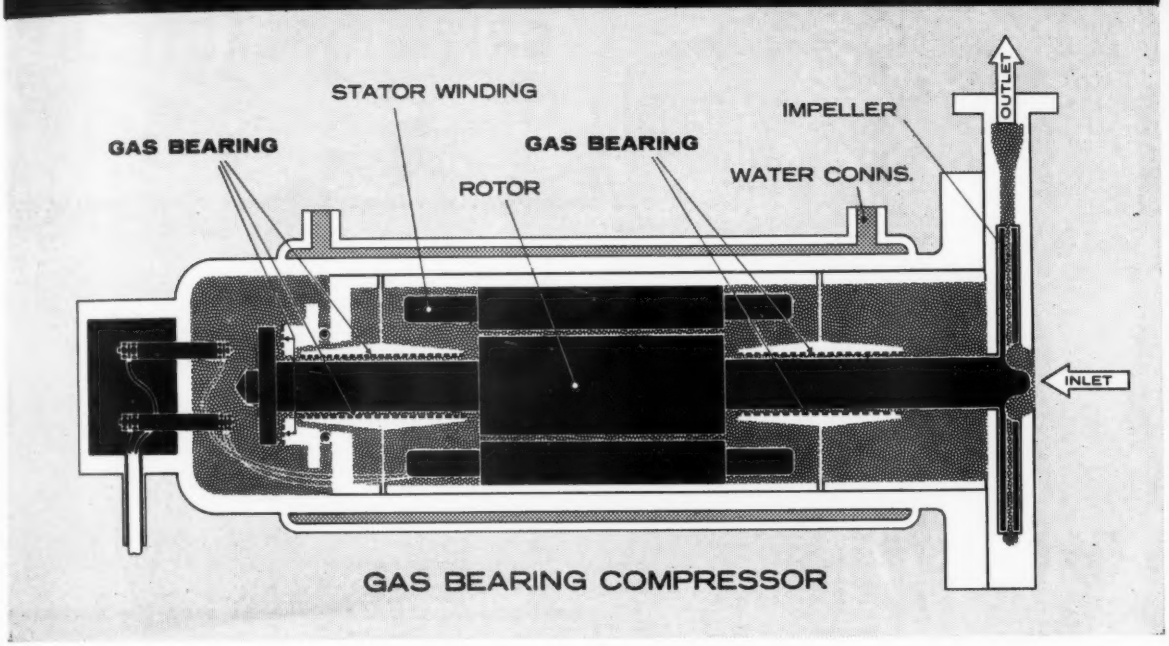
# Gas bearing compressors – totally enclosed, lubricant free – circulate gases up to 700°C, 2,000 psi, without contamination . . .




GAS BEARING COMPRESSOR

# ...ANOTHER ENGINEERING ADVANCE BY BRISTOL SIDDELEY

One of the largest manufacturers of motive power units in the world, Bristol Siddeley Engines Limited produce gas bearing compressors. The range covers a very wide performance capacity, from 0°—700°C gas operating temperature, 15—2,000 psi and 0.5—2,000 hp power input.

These Bristol Siddeley compressors have been designed specifically for systems where contamination from lubricants or leakage to atmosphere cannot be tolerated. Each unit, fitted with hydrodynamic-type gas bearings, is totally enclosed and no seals are required between the impeller and the bearings.

Gas bearings have several great advantages over oil lubricated bearings: the load-carrying capacity increases with speed, temperature and pressure; the bearings are supported on a film of the gas which is being circulated in the system, so there is no metal-to-metal contact under operating conditions and wear and maintenance are reduced to an absolute minimum; perfect cleanliness is preserved at all times.

**Applications**

Bristol Siddeley gas bearings were developed originally to meet the extremely fine limits of operating purity and precision of manufacture demanded by the advent of nuclear engineering. But gas bearings have many other applications where a rotating shaft must be supported in such a way that no contamination and leakage can be allowed and where the supply of chemically pure fluids or gases is essential: in the textile, chemical engineering, pharmaceutical, food storage and processing industries, to name but a few.

For further information about Bristol Siddeley gas bearing compressors and gas bearings, please write to H. J. Prince, Sales Manager, Reactor Components Division, Bristol Siddeley Engines Limited, P.O. Box 17, Coventry, England.

**BRISTOL SIDDELEY ENGINES LIMITED**



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## BRITISH REACTORS

**Low neutron capture cross section**

**High apparent density**

**Good strength**

**Ease of machining**

Nuclear grades of "Acheson" Graphite have now been supplied in considerable tonnages to the United Kingdom Atomic Energy Authority for Calder Hall A and B Reactors, Chapelcross, and for the new Atomic Stations now in construction by the Nuclear Power Consortia Companies. There is no doubt that the very high quality and moderating efficiency of "Acheson" Graphite have been thoroughly proved by full scale performance in present working Reactors.

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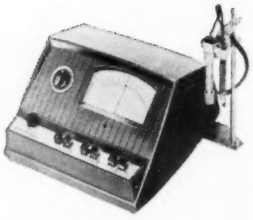
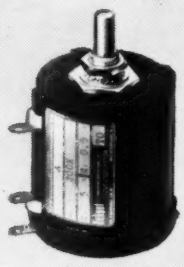


Zeromatic pH Meter

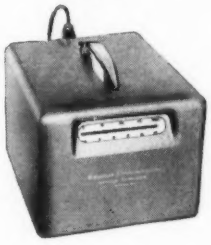
Duodial Precision Turns-counting Dial



Eput Meter • Digital Recorder

Industrial pH Equipment

Helipot Precision Potentiometers ▸

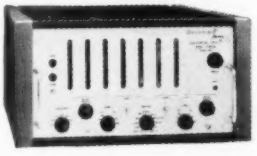


Portable Oxygen Analyser

Gas Chromatograph

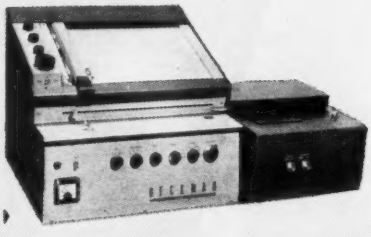
Dissolved Oxygen Analyser

123 Data Logger



Universal Eput and Timers

Infrared Spectrophotometer



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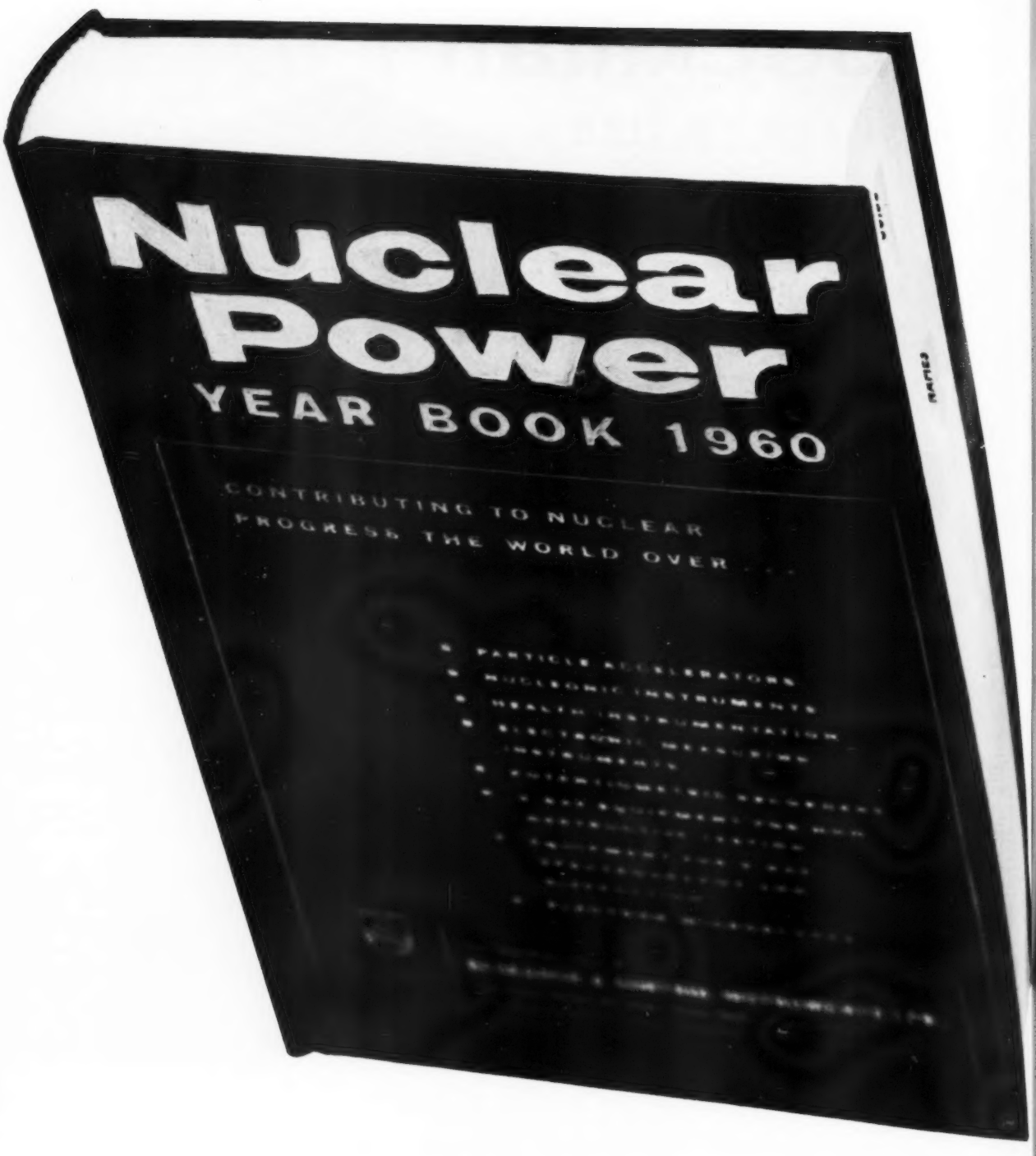
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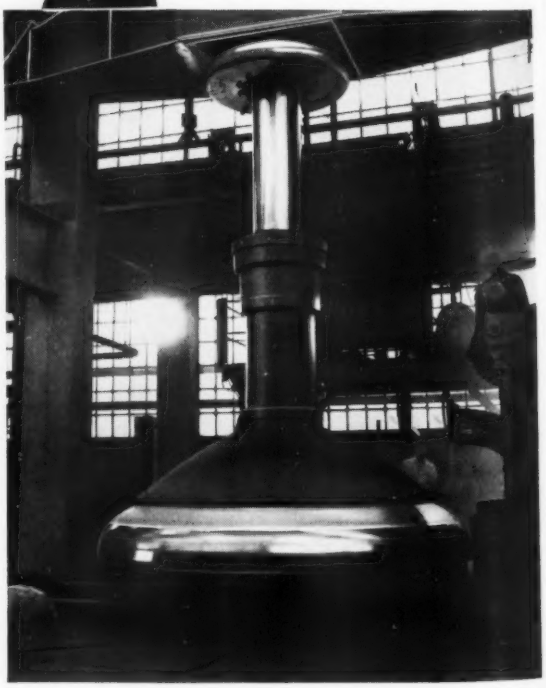
# Over a Ton of Aluminium Alloy spun to 10 ft. i/d x 1 5/8"

One of a number produced for pressure vessels to hold liquid air, this 10 ft. aluminium end was spun by Harveys on the Rotarpress. The 12 ft. flat discs needed for spinning these ends, which are believed to be the largest spun aluminium ends produced in this country, were formed by butt-welding two plates of aluminium alloy together.



The Rotarpress is one of the large-capacity units in Harveys Heavy Fabrication Department. It produces ends up to 15 ft. diameter and is adaptable over a wide range of knuckle radii and depths.

The contours of semi-ellipsoidal ends produced by the spinning process enable plate thickness to be reduced, and in most cases tool costs are eliminated. Enquiries are invited for ends only or for complete

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# IMHOFS Great advance in rak design!

Imhofs new Imrak International Rak is a completely universal flexible rack system. It can carry British, American and Continental fixings. It packs flat for easy storage or transportation. There are five standard types, each made in four different heights and four different plan sizes—a choice of 80 different standard raks in this new series! There is a choice of normal front panels, one-piece front panel or recessed front panels with removable door. Skilful design ensures an elegance of appearance that enhances but does not dominate the instruments. The standard hammertone finishes are ideal for reliability and long service; other finishes are available to special order

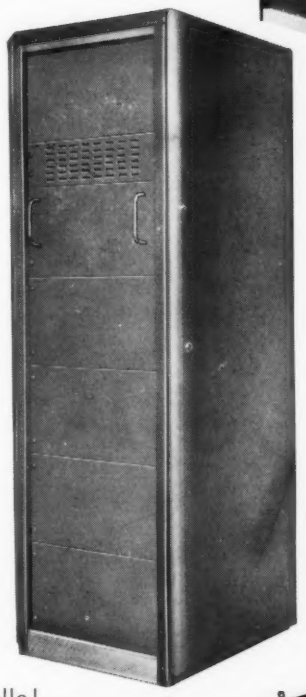
NEW!

## Ein grosser Fortschritt im Bau von Instrumentengehäusen!

Das neue "Imrak International" System von Instrumentengehäusen ergibt ein Höchstmass an Anpassungsfähigkeit. Teile britischen, amerikanischen und kontinentalen Ursprunges können untergebracht werden. Zum leichten Aufbewahren und Transportieren flach zusammenlegbar. Ausgeführt in fünf Normaltypen, jede in vier verschiedenen Höhen und vier verschiedenen Grössen der Grundfläche—eine Auswahl von 80 verschiedenen genormten Gehäusen in dieser neuen Reihe! Ebenso steht eine Auswahl verschiedener Vorderwände zur Verfügung, aus einem Stück hergestellte Vorderwände oder rückspringende Vorderwände mit abnehmbarer Tür. Sachkundig ausgeführte Linienführung ergibt ein schnittiges Aussehen, das die Instrumente hervortreten lässt, ohne sie zu unterdrücken. Die normale Fertigung mit gehämmerter Oberfläche ist für Verlässlichkeit und lange Lebensdauer besonders geeignet; andere Arten der Fertigung sind auf Sonderbestellung erhältlich

## Grand progrès dans le developpement des 'raks'!

Le nouveau Imrak International Rak fabriqué par Imhofs est un système d'étagère flexible et entièrement universel. Ce système peut porter des montages Britanniques, Américains et Continentaux. Il en existe cinq types normaux, fabriqué chacun en quatre hauteurs différentes, et en quatre différentes grandeurs de plan—en tout, un choix de 80 différents raks normaux dans cette nouvelle série! Il y a un choix entre des panneaux avant normaux, des panneaux avant en une seule pièce et des panneaux avant à embrasure, comportant une porte amovible. Un dessin soigné donne lieu à un fini élégant qui fait ressortir les instruments san les dominer. Les finis normaux au marteau sont l'idéal pour la sûreté et la durée du fonctionnement, d'autres finis peuvent être obtenus sur demande



NUEVA!

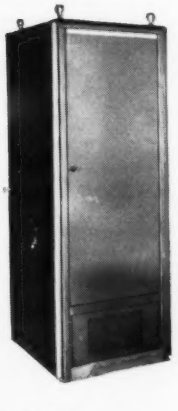
## ¡Un gran adelanto en el diseno de bastidores!

El nuevo Imrak International Rak de Imhof es un sistema de bastidores completamente universal y flexible. Se puede facilitar con montaje británico, americano o continental. Se empaqueta plano para mayor facilidad de almacenamiento o transporte. Existen cinco tipos normales, cada uno de los cuales se suministra en cuatro alturas distintas y en cuatro tamaños de planta distintos, ofreciendo una variedad de 80 bastidores normales entre los que elegir. También se ofrece una variedad de paneles frontales normales, paneles en una sola pieza y paneles embutidos con puerta desmontable. Su concepción esmerada le da un estilo atractivo que realza los instrumentos sin dominarlos. Los acabados normales al martillo son ideales por su seguridad y larga duración, pero se dispone de otros acabados contra pedido especial

neue!

# imrak international series

nouvelle!



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**2** Strong, accurately-made framework of pressed steel gives exceptional rigidity

**3** Captive nut system of panel mounting gives maximum flexibility

**4** The standard specification includes a host of special features—locks, quick-release and lift-off hinges, decorative trims, provision for lifting eyes and many more

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**Voyez pour vous-même:**

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**3** Le système à écrou indesserable du montage de panneau, donne une flexibilité maximum

**4** La spécification normale comprend une multitude de caractéristiques spéciales—serrures, charnières à déclenchement instantané et amovibles, garnitures décoratives, dispositions pour hausser le croc, et autres

**le ofrece:**

**1** Cinco tipos distintos, a saber, el de cubículo, el cerrado, el de ventilación forzada, el de ventilación inducida y el completamente cerrado

**2** Un armazón de acero prensado, robusto y fabricado con precisión, y con una rigidez excepcional

**3** El sistema de tuerca imperdible que se emplea en el montaje de los paneles y que proporciona flexibilidad máxima

**4** La especificación normal incluye numerosas características especiales, tales como cerraduras, charnelas de acción rápida y amovibles, guarniciones decorativas, disposición para ojos de izar y muchas más

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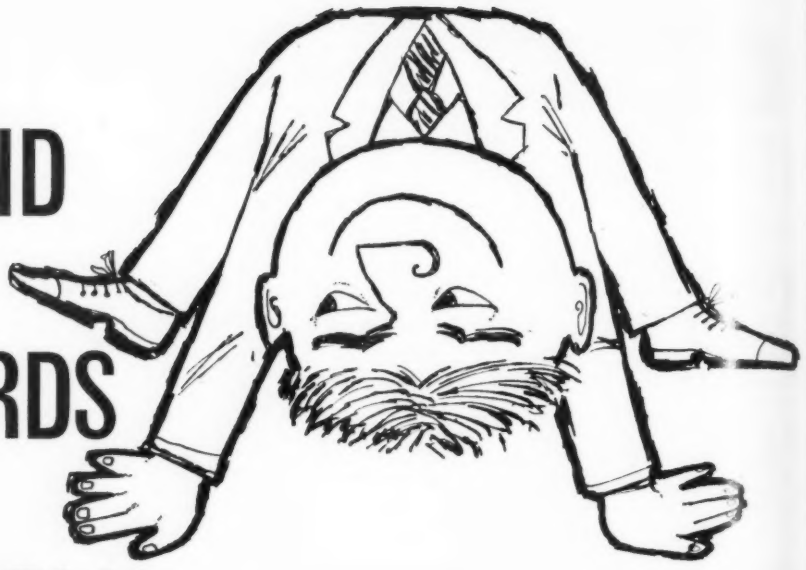

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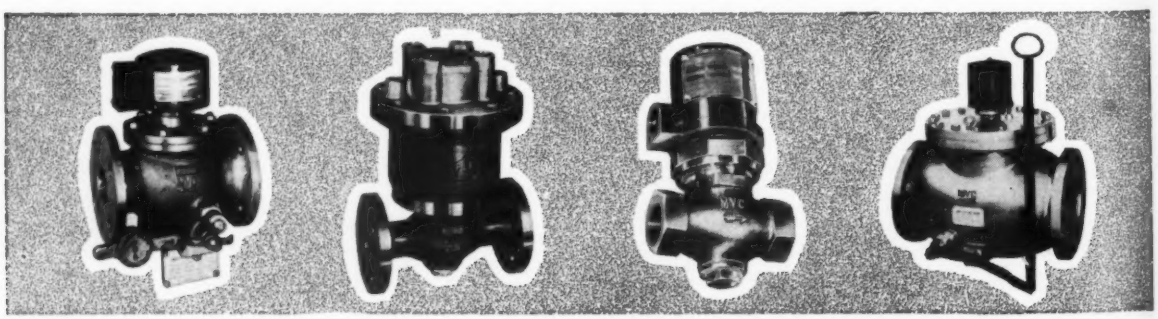

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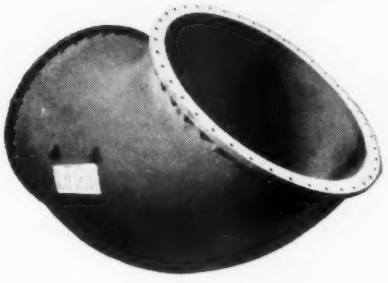

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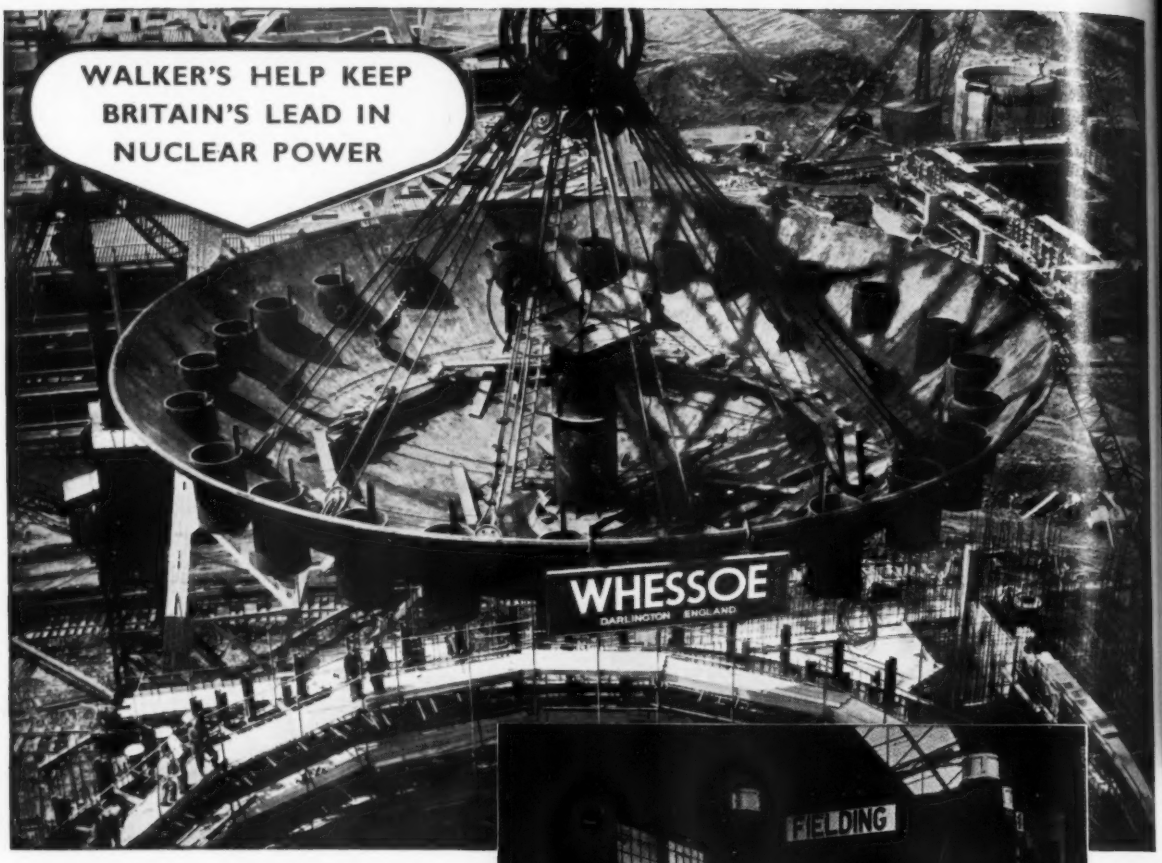


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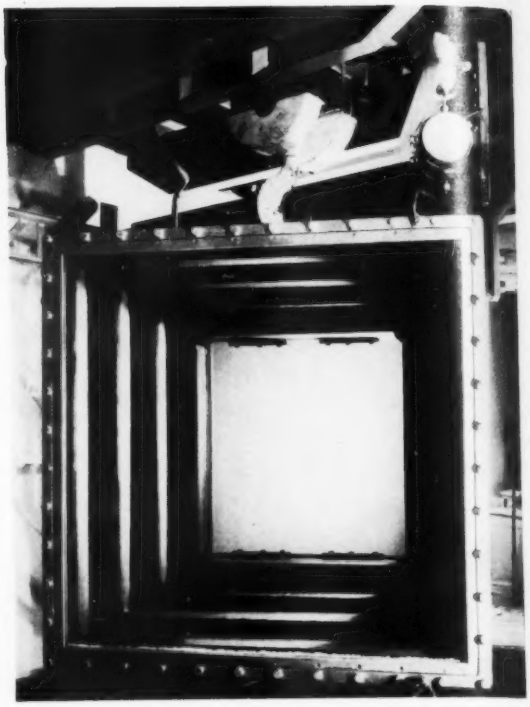

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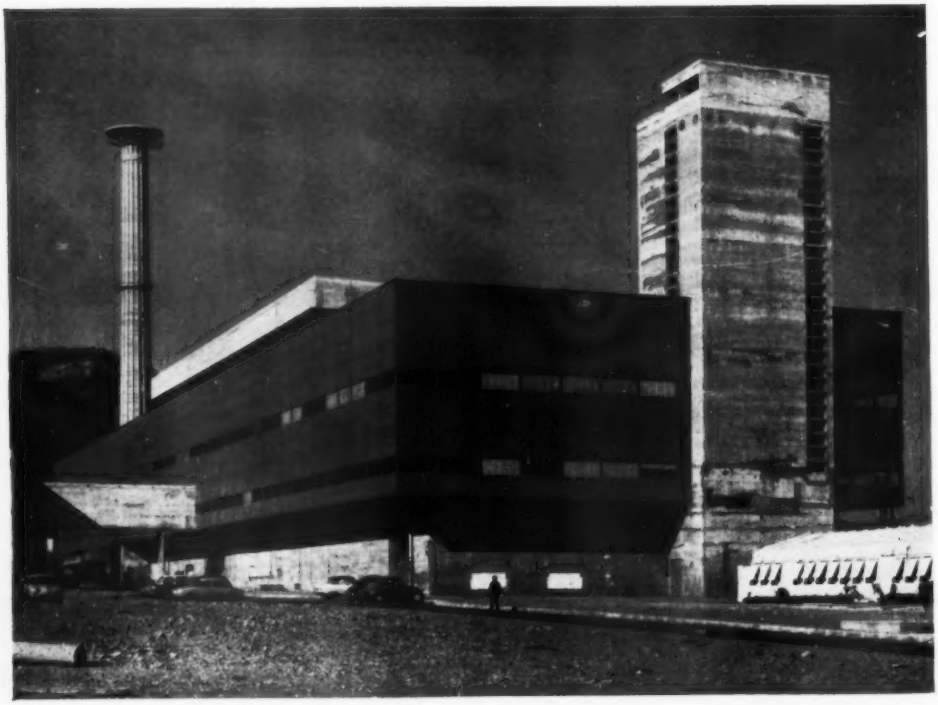

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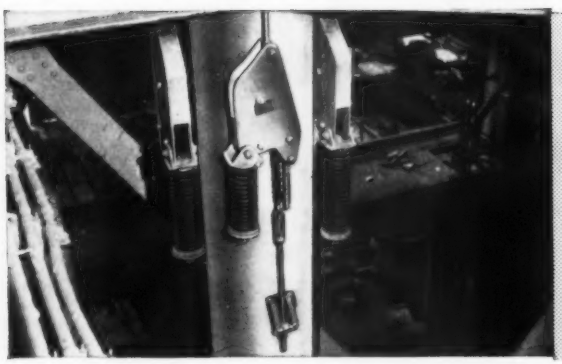

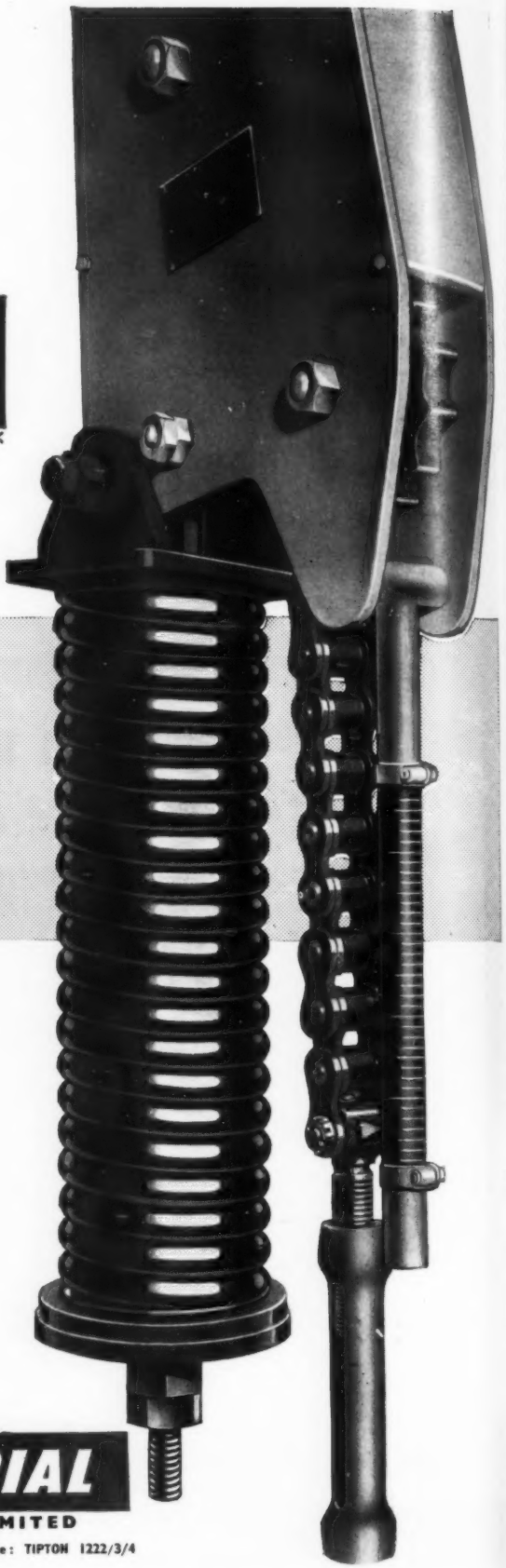

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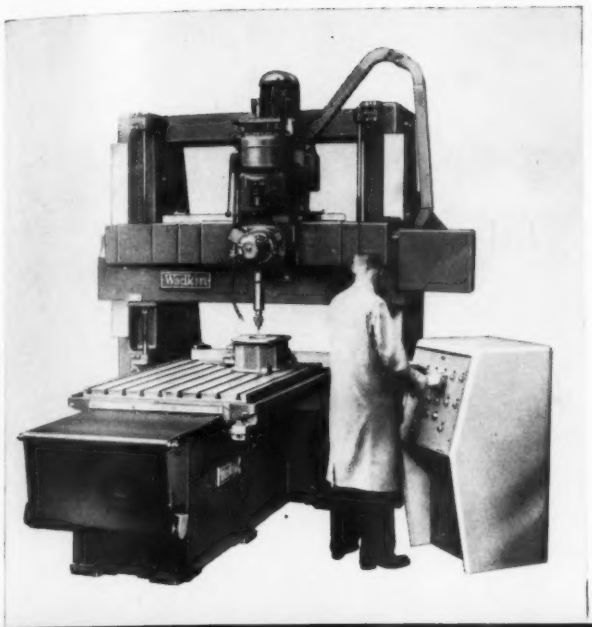

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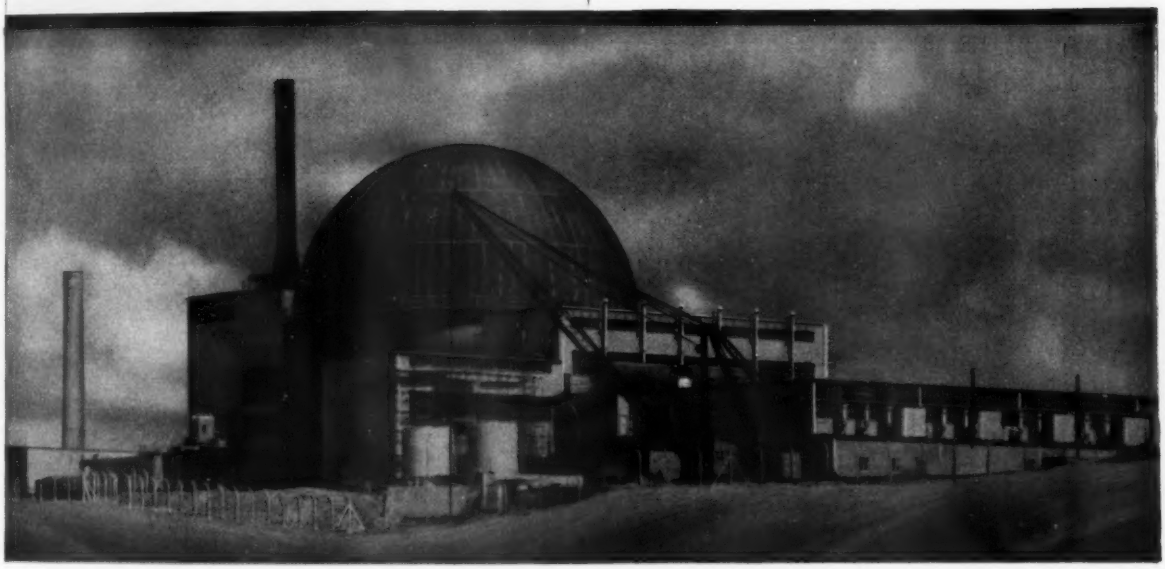

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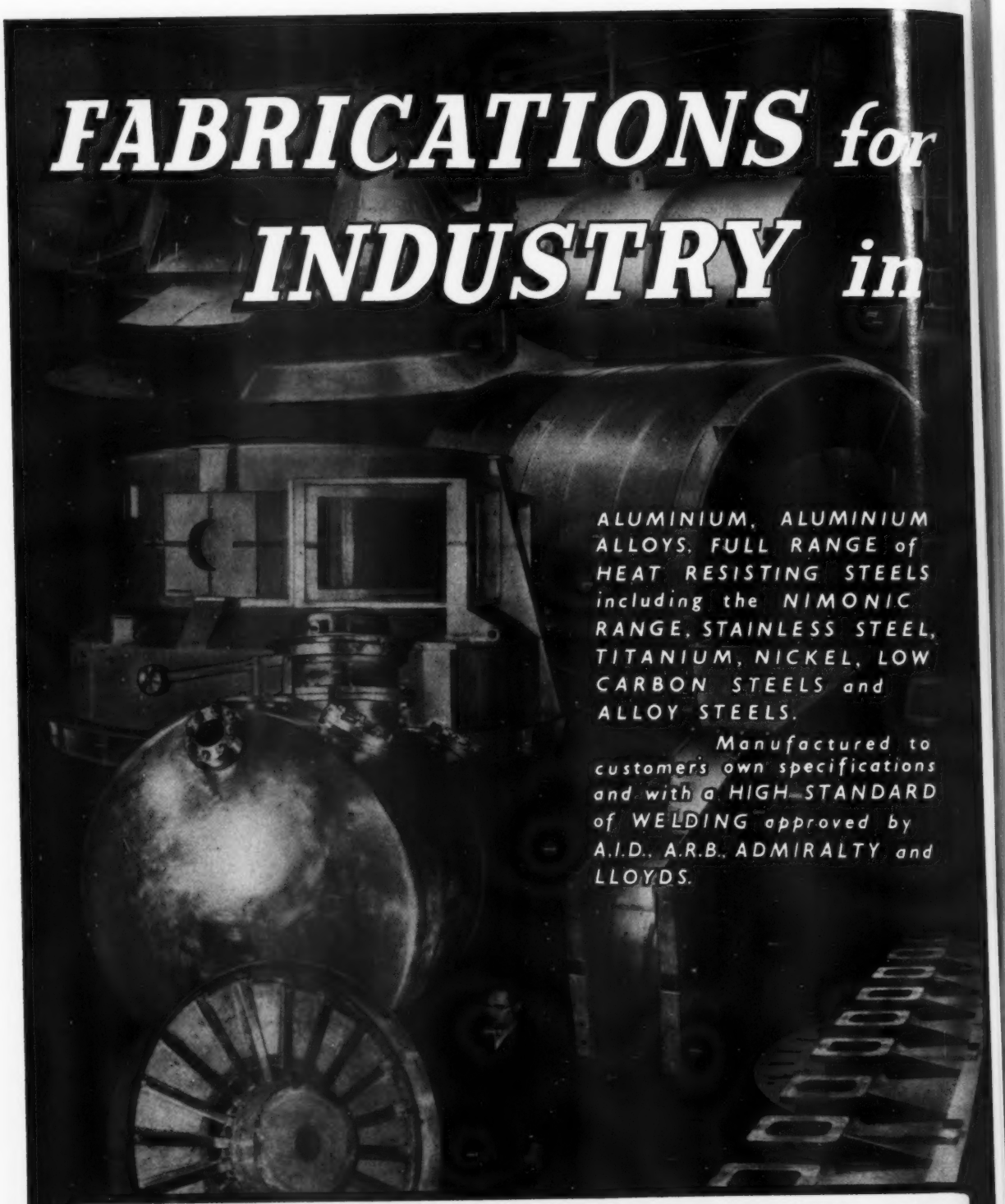

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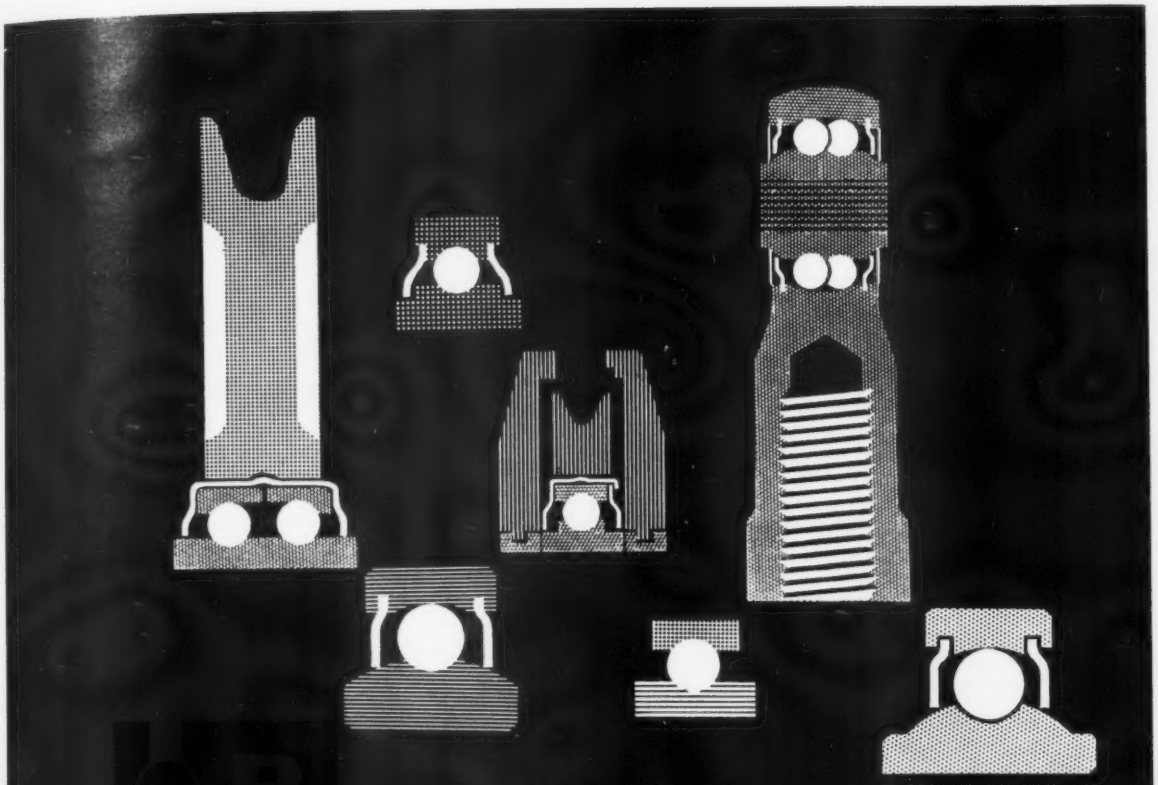

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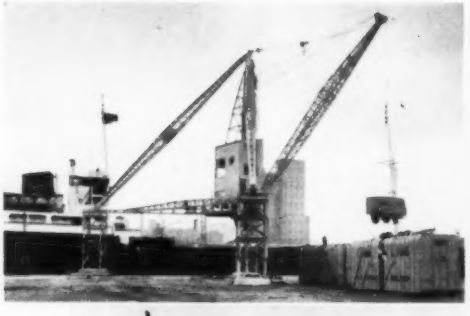

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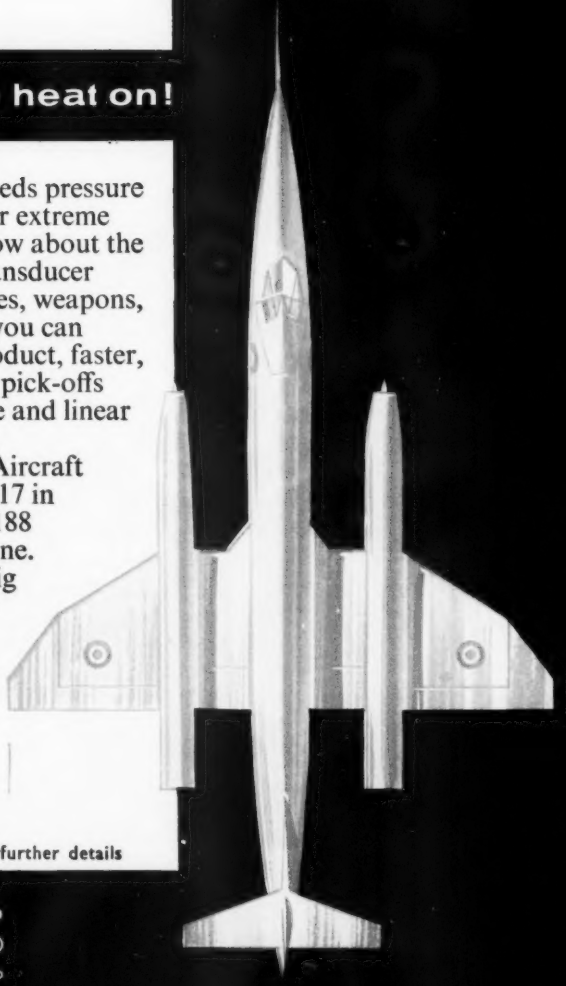

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Nuclear Power
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MAY 1960 VOLUME 5 NUMBER 49

# VIEWPOINTS *letters to the Editor*

## Emergency shut-down devices

SIR: I have had a number of enquiries from readers about remarks I made in my article reviewing reactor engineering developments in 1959 (NUCLEAR POWER, January 1960). One of these which came from the USA was rather significant.

Why is it, said the enquirer, that the latest British reactor designs are fitted with 'emergency shut-down devices'? Has some new discovery been made which suggests that there is danger of a runaway accident? It seems to me that this is a legitimate question which should be answered, so I think that my reply which follows may be of general interest.

The decision to incorporate these devices has no connexion with any new ideas about the kinetics of gas-cooled reactors. The positive moderator temperature coefficient of these reactors when operating without full plutonium build-up considerably exceeds numerically the negative coefficient of the fuel. Thus the reactor is inherently unstable; if super-criticality is not controlled deliberately by means of absorbers, the temperature can rise continuously until a melt-down of fuel occurs.

In other words, the safety of the reactor is completely dependent on the correct operation of the control rods, which must be capable of entering the core at all times. Only one circumstance could conceivably cause them to jam, viz. a gross distortion of the core sufficient to physically block the control rod channels. I understand that the Japanese thought this could happen under earthquake conditions and the boron steel ball device was developed by the GEC for them. The balls will run in even after the core is tipped over at an angle and will render the reactor sub-critical. Most importantly it is possible to design such a device so that it can be operated without damage to the core and it can be re-loaded again without difficulty, e.g. by using compressed air.

What I think has happened is that the authorities have realized that such a device could do no harm in all reactors and have specified it for future designs.

I must explain that the above represents my opinions on this subject as a neutral observer but I would like to say that I think that more authoritative statements should be made either by the AEA or the CEGB about matters of this kind in order to prevent undesirable speculation. In the USA, Hazards Reports are available to the public on all reactor projects and I think it is highly desirable that we should have something similar in this country.

*Chief Engineer, Nuclear Dept., Kennedy & Donkin* — R. F. W. GUARD

## Springfields uranium plant

SIR: My attention has been drawn to a quotation in the January 1960 issue of NUCLEAR POWER. On page 130 you refer to a comment I made at the BNEC Symposium on the Second Uranium Plant at Springfields. You quote me as having implied that 'as the design calculations had not been borne out in practice, in future plants they would try to avoid stage interdependence'.

Whilst this is a correct quotation it should have been pointed out that I was referring to one specific point in the design of one section of the Second Uranium Plant, and not to the whole of that plant as your comment would infer.

The comment on design calculations referred only to the pressure drop across mixer settler contactors and this difficulty can be overcome by avoiding stage interdependence in the design of the contactors.

*Deputy Chief Engineer, (Windscale Plants), Risley, Lancs.* — L. P. SHORTIS

## Indian fuel elements

SIR: Referring to page 94 of the January 1960 issue of NUCLEAR POWER, may I point out that the Atomic Energy Establishment Trombay has already made some of the fuel elements for the Canada-India Reactor and is in a position to supply the entire first charge but, in order to meet the wishes of the Canadian authorities, it has been mutually agreed to use some Canadian fuel elements in the first charge; more than half of the first charge, however, will consist of Indian-made fuel elements.

The pool-type reactor, Apsara, was entirely designed, constructed and commissioned by personnel of the Trombay Establishment, the only outside assistance being in the supply of fuel elements by the UKAEA as these fuel elements could not be made in India as they contain enriched fuel.

*Government of India, Atomic Energy Establishment, Bombay* — E. C. ALLARDICE

## PUBLISHER'S COLUMN

Whilst change for the sake of it is not a good thing, the hall-mark of a successful journal is its constant watch on readers' requirements. We have felt for some time that certain regular features need a new approach, and with this issue some changes have been made. The new *Business News* feature will report concisely for management on both home and overseas company activities while short items on new engineering ideas and developments will now be included in the *Progress in Industry* feature. The *Points from Papers* feature will be devoted to important reports, surveys and papers and a selection of new reports will be listed. The importance of a good general news coverage has been recognized by extending the length of *Worldview* to eight pages.

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# OPINION

## Overhaul export tactics now

BRAZIL'S DECISION to invite tenders for a gas-cooled graphite-moderated type of power station and the revival of interest in India (see *Worldview*, this issue) have increased the possibility of the United Kingdom gaining another export order. So far only two have been secured (Japan and Italy), and it may be profitable to take a close look at British tactics and see if they might be modified for the future. It seems safe to assume that British engineers will continue to design the best power stations of this type: if the country fails in competition with overseas groups, it is more likely to be for reasons involving money or politics.

The need for Government financing of exports to meet similar competition overseas is, of course, increasingly necessary. Too often, British bidders are faced with having to match long-term low-interest loans for construction and artificially low fuel prices, plus generous terms for the supply and re-processing of fuel backed by other governments. The normal assistance the British bidder gets is through the Export Credits Guarantee Department, which, however, does not provide finance for the exporter, but only guarantees insurance. This undoubtedly makes it easier for the prospective exporter to get a loan, but normally only at prevailing home interest rates.

There have been signs recently that the Atomic Energy Authority is prepared to lower its prices for fuel elements; it could be maintained, however, that the best policy would be to go all the way and start quoting now a figure which really reflects the world market price of uranium, rather than waiting for the expiration of existing contracts with producers.

The Authority has also improved the policy on fuel element guarantees. During the course of 1959, it agreed to buy back elements which failed almost immediately at the actual selling price; it seems, though, that the policy of allowing a constant buy-back price over a burnup range of about 1000 MWd per tonne centred on 3000 MWd per tonne is still in force. This means that the lower figure—2500 MWd per tonne—is used when negotiating for export orders and this compares unfavourably with that used by other countries.

A factor which has undoubtedly hampered export success in the past is the fog of uncertainty surrounding declassification. It has not been unknown for a member of a British team to refuse information requested by a prospective buyer on the grounds that it was classified, only to be told that another British group had disclosed information on the same subject quite freely. If the United Kingdom is to reap an adequate benefit in the export market from its immense investment in the atomic energy industry, British groups must be free to discuss their reactors with prospective customers in as much detail as may be required. Two of the most important subjects are concerned with graphite and the effects on it of neutron irradiation, and, of course, operating experience with Calder Hall and Chapelcross; this includes in-pile irradiation experiments. It seems fantastic to expect overseas countries to buy a Calder Hall-type reactor while denying them the basic data from which they may verify the maximum fuel element burnups achieved in what are, after all, the only stations of this type actually working in the United Kingdom, or disclosing data to one or two selected persons in conditions of great secrecy.

In some cases, material is classified for quite arbitrary reasons of commercial security which have nothing whatsoever to do with official secrets. In other cases the reason for classifying or merely withholding information is quite obviously to try and keep worrying problems hidden until they have been solved. Considerable damage has been done to the prospects for British-designed reactors by an appalling lack of frankness on such subjects as positive temperature coefficients, instability, and Wigner energy storage. When unforeseen technical problems are encountered, it is in the long run far better to tackle the subject out in the open, even when it involves a serious amount of re-designing, than to work feverishly behind a wall of secrecy which cannot in the end be maintained. The facts will leak out somehow, and sometimes in a distorted and highly-coloured form.

When design changes do become necessary after a contract has been given, the cost of these should, of course, be borne by the seller, and unwillingness to do this in some instances has not improved British prospects: it merely implies that the designers are not completely confident of their product. The lead given in America last year by the Westinghouse Corporation (*Worldview*, November 1959) in guaranteeing their prices was a sensible and praiseworthy move.

Turning to the matter of safety, British groups have found to their cost that the simple statement: 'the design has been approved by the Atomic Energy Authority,' has not always, by itself, completely reassured prospective purchasers. The American method of preparing detailed safety reports for each reactor type and making them freely available to possible buyers well before putting in an actual bid has proved so obviously superior to the British way of answering questions only when asked, that the industrial groups have very much improved their practice in this respect. It cannot be emphasized too strongly that every conceivable accident should be discussed spontaneously and openly with any possible buyer.

The complete story of Britain's efforts to sell reactors overseas in the last few years is a very complex one. Much has been learned and there seems no reason to doubt that if properly backed by the government and the Atomic Energy Authority, the British atomic energy groups will yet make a substantial contribution to exports.

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*A Wakefield-Dick research chemist investigating the effects of radiation on lubricants.*

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**NUCLEOL 522** A radiation resistant lubricant based on selected mineral oils of high aromaticity and containing special inhibitors.

**NUCLEOL G120** A grease gelled with a new compound, and specially inhibited. Designed for the lubrication of control actuator bearings operating at the lower radiation levels.



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# Worldview

*the month in atomic energy*

## EUROPE

### GEC bids against strong French competition in India

The existence of strong French competition in the bid to build India's first nuclear power station was brought out by Mr. R. N. Millar, managing director of the General Electric Company's Engineering Group. Mr. Millar, who recently returned from a two week trip to India and Japan, told NUCLEAR POWER that the GEC would be submitting a turnkey tender for two 150 MW reactors for the Indian station in the first quarter of next year.

'It's not certain that we will get the order but it's on the cards that Britain will get the order', he said. 'Our principal opposition comes from France. This is the first time we have come up against French opposition and they can be considered as serious competitors. In the long run, I think credit will be the deciding factor'. The GEC, Mr. Millar added, would get the usual credit insurance from the Exports Credits Guarantee Department but it was unlikely that there would be Government assistance on the scale given by other countries.

Confirmation of the existence of a French mission in India last month comes from reports from Paris. These say the mission had a proposal to submit to the Indian Government to build the station. Backing this bid was the existence of the Indo-French agreement providing for large French credits for equipment and development.

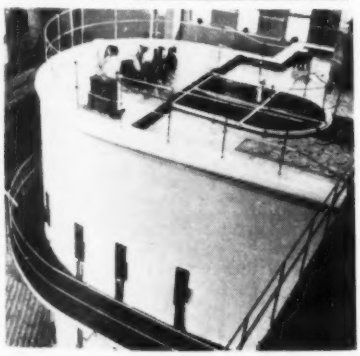
Mr. Millar said he did not know the French companies concerned in the Indian bid but he did know that there had been a representative from the Commissariat à l'Energie Atomique (CEA) in Japan who, however, was concerned with dealing with licences for French designs rather than with selling stations. His own visit to Japan had been concerned with checking up on a few details of the Tokai-Mura contract.

Mr. Millar left the United Kingdom at the end of March on his visit at the invitation of Dr. Homi Bhabha, head of the Indian Atomic Energy Commission. 'I had discussed the matter with Dr. Bhabha on several occasions and he invited me to come to India to talk the matter over', Mr. Millar stated.

'India really wants to buy a Calder-type reactor and to build natural uranium reactors so as to get plutonium to use in advanced-type reactors', he added. 'We shall be sending out our engineers in about six months time to investigate further details and to see if they (India) can manufacture further plant'. The Indian plans called for four stations, each with two 150 MW power reactors.

However, Mr. Millar did point out that there was one possible snag. That concerned the International Atomic Energy Agency safeguards over the use of plutonium. The Russians had indicated that they were not concerned about applying these and the Indians said that if the British applied these safeguards, they would not buy the reactor. They were willing to give an undertaking not to use the plutonium for military purposes but were not keen on the idea of having a large number of inspectors at their plant. 'I will have to discuss this matter with the appropriate authorities here', Mr. Millar stated.

Asked whether the United States would probably sell its reactors to India, Mr. Millar replied: 'I think it's possible that they (India) might buy one of two US reactors but they really want to buy natural uranium reactors'.



**USSR** This recent picture shows the low-powered research reactor now in operation at the Georgian Science Physics Institute

### The Royal Navy gets a research reactor

*London* The Royal Naval College at Greenwich, London, is to be supplied with a light water-moderated natural uranium subcritical facility made and marketed by Miles Hivolt Ltd. It will be operated together with a pulsed neutron source and is based on a design produced for the University of Birmingham's Physics Department with the help of the Department of Scientific and Industrial Research. Total cost is estimated at £13,500 including about £5000 for the subcritical unit.

The combination of the pulsed or continuous neutron source and the subcritical reactor may be used to study many of the important parameters of nuclear reactors. As well as studying the steady state conditions, the dynamic characteristics can now be predicted and studied. A further advantage for teaching facilities is that the equipment can be turned off and made completely safe.

In the design, the lattice plates are vertical with the natural uranium rods placed horizontally in between. Reflected and non-reflected experiments are possible using one of two tanks which can be raised into position and then filled with demineralized water.

The neutron generator uses a 150 kV positive ion accelerator with suitable neutron producing targets coupled to the reactor via a stainless steel drift tube which can be passed through the reactor in any one of four positions.

## Worldview

• **United Kingdom** IBM (UK) Ltd. have announced that the Central Electricity Generating Board have placed an order for a 709 data processing system to use for work on the design of nuclear reactors. Cost is expected to be over £400,000 and installation is to be in early 1961.

• **IAEA** The proceedings of the International Symposium on Medical Radioisotope Scanning held in Vienna in February 1959 have been published by the International Atomic Energy Agency.

• **Belgium** The alternator for the pressurized water reactor BR3 at Mol has been completed and is being sent there by the main contractors, Ateliers de Constructions Electriques de Charleroi.

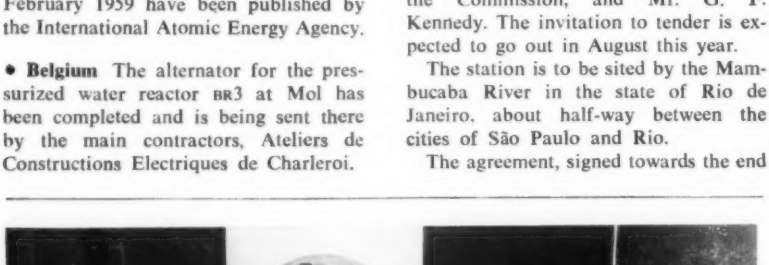
## Tenders to be invited for Brazilian reactor

*London* Kennedy and Donkin, the consultant engineers, have now signed a formal agreement with the Brazilian National Commission for Nuclear Energy for the preparation of an invitation to tender for a gas-cooled graphite-moderated reactor in the 150–200 MW range (see *Worldview*, March). Signatories were Admiral Octacilio Cunha, president of the Commission, and Mr. G. F. Kennedy. The invitation to tender is expected to go out in August this year.

The station is to be sited by the Mambucaba River in the state of Rio de Janeiro, about half-way between the cities of São Paulo and Rio.

The agreement, signed towards the end of last month, also provides for Kennedy and Donkin to appoint American consulting engineers to work with them.

Meanwhile, it is reported that Sr. Octavio Augusto Dias-Carneiro, a member of the Brazilian National Commission for Nuclear Energy, has been appointed as superintendent of the Mambucaba project. Plans are also being made by the Brazilian Government to work out legal rules on third party liability and insurance in connection with its nuclear power programme, particularly the Mambucaba project, and a legal expert from the International Atomic Energy Agency is going to Brazil to advise on these questions.



**LATINA STAFF AT CALDER HALL** Italian engineering staff who will hold key posts in the British designed nuclear power plant at Latina, near Rome, undergoing part of an intensive training course at Calder Hall to provide them with operating experience. They are under the direct supervision of UKAEA staff. The special facilities afforded by this course, which includes a period at Calder Operation School as well as a period in the power station itself, are similar to those which have been available to the UK Central Electricity Generating Board, South of Scotland Electricity Board and Consortia staff for some time

## Dounreay shuts down for experiments

*London* The 15 MWe fast breeder reactor at Dounreay, which has been shut down for three months, is to have modifications carried out to the core. The shutdown is according to programme and completes the first phase of experiments, says the UK Atomic Energy Authority. The reactor has been working at a low power level since it went critical on November 14, 1959.

The changes to be made in the core are to make it a more flexible facility so that a wider variety of types of fuel can be tested. The core is hexagonal, 21 in. high and 20·5 in. across the flats and is made up of 45% enriched uranium fuel elements surrounded by a blanket of 1827 natural uranium rods, eight feet long and 1¼ in. diameter. As an experimental tool, the reactor has been designed so that minor and major components may be easily replaced when different designs have to be tested.

Since the reactor went into operation, an intensive programme of physics and research has been carried out. This has aimed at providing information for the operation of the reactor at higher power levels and to help in the design of a prototype fast breeder reactor.

## UK Nuclear Installations Act now in force

*London* With the coming into force on April 1 of the Nuclear Installations (Licensing and Insurance) Act, the public can claim compensation direct from the operator of a nuclear installation for personal injuries or property damage caused by the release of radioactivity on a licensed site.

The regulations are also concerned with injury or damage caused or likely to be caused by any emission of ionizing radiations or by radioactive or toxic substances and the procedure to be followed. They would also apply if there were an accident during the disposal of waste or the transport of irradiated fuel. In addition, the Act provides for regulations to cover the safe design, siting, installation, construction, operation, modification and maintenance of a nuclear installation.

The Act does not require the installations of the Atomic Energy Authority to be licensed but nuclear installations already operating which required a licence on April 1 were two research reactors owned by private firms. Other licences which came into force are those relating to the five nuclear power stations being built by the Central Electricity Generating Board. However, at these sites it is unlikely that substantial radiation hazards will possibly arise for a year or more.

## Suisatom progress held up

*Berne* Main obstacle to Suisatom AG's plan to build an experimental power station of about 10,000-15,000 kW at Villigen in the Aargau is lack of government aid. The company's annual report says an application to the Government for an interest-free loan redeemable in 15 years had to be withdrawn although Suisatom believed that the building of an experimental nuclear power station would have justified such assistance. The report also disclosed that the Govern-

ment had asked the company whether it would drop its own project for an American-type boiling water reactor in preference for a Swiss-designed reactor to be built by two industrial groups. Suisatom would only give up its original plan if the new undertaking had any real prospect of success says the report.

## US and Euratom fall out

*Brussels* Disagreement on the way the US-Euratom research programme should be tied to the power reactor construction proposed for after 1963 has been expressed by the Euratom Commission. The US authorities were told that the Commission would not agree to issuing invitations for the second part of the power reactor programme unless it were recognized that the research programme should not be too closely tied to power construction plans. The present surplus of conventional forms of energy made it necessary for flexibility in the interpretation and carrying out of the agreement for cooperation.

The Euratom statement added that the US had said it was ready to open negotiations on lightening, as far as possible, the financial obligations of those taking part in the power programme.

The United States was also prepared to discuss the replacing of the present systems which provided deferred payments for the purchase of uranium-235 by Euratom members with another making the fuel available on hire.

**WORK AT WINDSCALE** The latest progress picture of work on the UK prototype advanced gas-cooled reactor (AGR) being built at Windscale, Cumberland, shows the first of four heat exchangers being lowered into position within the secondary shield inside the containment vessel. The ultimate objective of the AGR is to gain operating experience of a carbon dioxide-cooled, graphite-moderated power reactor using a different type of fuel canning material from Calder Hall and working at a higher temperature

## OEEC forecasts electricity supply position

*Paris* Another forecast as to when nuclear power will become competitive has been made in the 10th annual report of the Organization for European Economic Cooperation's Electricity Committee. This would happen in all parts of Europe towards 1975 on the basis of about 6000 hours per year running time though the report says this is 'the most optimistic assumption'.

The safest assumption, the report adds, would be that nuclear energy will not succeed in becoming competitive with conventional energy before 1975. Should that be so, after the 5000 MW brought into service in 1965, the rate at which new plant will come into service should settle down at the 1965 level i.e. at one 1000 MW per annum. Nuclear capacity would thus be only 15,000 MW by 1975.

The maximum nuclear capacity which can be reasonably expected for the OEEC countries as a whole is said to be 55,000 MW. This figure could only be exceeded if nuclear power stations became competitive with conventional thermal plants for running times of less than 6000 hours a year.

The report also discusses the outlook for the electricity supply industry which it describes as extremely favourable. Member country forecasts up to 1964 predict an average increase in consumption of 6·5 per cent per year without any perceptible sign of saturation.

Long-term requirements and the means by which they can be met are also discussed. Country estimates suggest that power consumption in 1975 should be about three times higher than in 1955. The period in between should see a gradual decline in the part played by hydro power due to the exhaustion of more profitable sites and the first contributions by nuclear energy.

Among points made in the report's conclusions is a recommendation that it would be wise to base investment programmes to a greater extent on long-term forecasts of demand. Power consumption was increasing extremely regularly; long-term programmes would eliminate as far as possible the effect of short-term fluctuations which greatly hampered civil engineering firms and the manufacture of equipment of all kinds.

• **Italy** Professor Felice Ippolito, secretary general of the Italian National Committee for Nuclear Research, has been confirmed as chairman of the Advisory Committee of Euratom's Supply Agency.

## Research facility at Padua

*Padua* A natural uranium subcritical assembly at the Upper School of Applied Nuclear Physics of the Italian National Committee for Nuclear Research (CNRN) at the University of Padua is expected to go into operation shortly. The fuel is being supplied by CNRN and is being prepared at the Committee's laboratory in Milan.

## German isotope uses increase

*Bonn* Use of radioisotopes by West German research institutes and industrial firms is increasing rapidly according to a recent statement by the West German Atomics Ministry. This said that the number of concerns importing radioisotopes more than doubled last year compared with 1958. A feature of this was that institutes and firms generally requested units of much smaller radiation power than in the previous year.

## Italian scientists protest

*Rome* The Managing Council of the Nuclear Physics National Institute recently called the attention of the Italian Parliament to the need for the government to pass legislation and make economic provisions to help Italian scientific research. The Council pointed out that the legislative-financial status of nuclear research had not made any progress since autumn last year.

This follows closely the pattern established by the Physical Research Workers Union and representatives of the Ispra Centre Research Association earlier this year when they expressed dissatisfaction at the state of nuclear research in Italy. They also asked the Government to face up to and to solve this question.

## UK power costs again

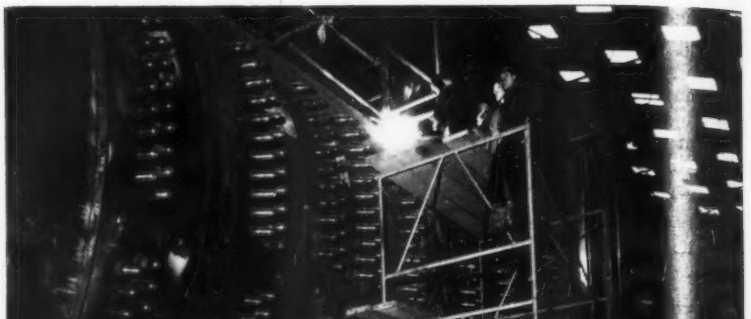
*London* The break-even date for nuclear power costs would probably be within ten years, according to the Minister of Power. He was asked recently in the House of Commons about the trend of comparable building and running costs between oil, coal and nuclear power stations. His forecast takes into account the fall in the uranium price and the drop in capital costs of nuclear power stations. The Minister said that neither building nor running costs could be precisely forecast.

## Bleak future for marine organic-moderated reactor ?

*London* The Organic Moderated Reactor (OMR) can probably be ruled out as a long-term marine project because of limits on the temperature of the coolant stream to 370°C (692°F) says Dr. T. W. F. Brown, Director of The Parsons and Marine Engineering Turbine Research and Development Association. Above that temperature, he says in a review of marine engineering, read to the Institution of Naval Architects, the polymerization rate would be far too high. Other bars are fire risks and the disposal problem of liquid wastes. However, it was probably the cheapest reactor offered at present for marine use.

## Strontium rise and fall

*London* The average level of strontium-90 in milk over the United Kingdom for the 12 months ending June 1959 increased by about 40% over the 12 months average ending December 1958, says the second report of the Agricultural Research Council's radiological laboratory. However, figures for June 1959 indicate that a decline in strontium fallout has already begun. The document, published by the Stationery Office, records the levels in milk during the first half of 1959 and in pasture and animal bones during the latter half of 1958.



**PROGRESS AT HUNTERSTON** Work is now going on round the clock on vessel fabrication at the Hunterston nuclear power station being built for the South of Scotland Electricity Board by The General Electric Co. Ltd. This picture shows one of the steam-raising units nearing completion

## Europe must depend on nuclear power

*Paris* Europe will again have to turn to nuclear energy in 'a few years'—at most 10-20—to avoid dependence on imports, says the second annual report of the European Nuclear Energy Agency. Economic recovery and industrial expansion within that time would lead to an energy demand that could not be satisfied by conventional fuels, at least without resulting in a growing burden on foreign payments, and perhaps even an inability to satisfy energy requirements.

However, the report points out that because of the cutting down of certain programmes and the delay in carrying out some projects, the maximum forecast of nuclear energy production in 1965 would be 7000 MWe against an earlier forecast of 8500 MWe. By 1975, production should rise to 35,000 MWe.

The cost of electricity during the period 1960-65 from nuclear power stations would be between 0·85 to 1·5 cents per unit (0·73 to 1·3d). This would be appreciably above the average cost of conventionally generated electricity in the same period (about 0·6 to 0·94d per unit) although it indicated the possibility of the economic use of nuclear power stations in certain regions. But, the report says, the estimates made at this stage are subject to reservations because of lack of nuclear power plant operating experience. These uncertainties concerning the economics of nuclear energy are of particular importance in a buyer's market where production costs for the different forms of energy become a dominant consideration.

Consequently, European countries must take full advantage of the respite offered by the temporary abundance of conventional energy to gain experience, develop and improve reactor types, investigate new types and solve the technical problems still outstanding. Joint action was essential if the countries were to cover the full field of research and experiment which far exceeded their individual capacities and if they were to make sufficiently rapid progress in developing the new techniques demanded by the fundamental transformation of their basic industries.

Other points from the report are:

*Eurochemie* The construction of the plant and laboratories, which should be finished in 1963, will be carried out on an international basis. Negotiations are going on to find a formula to associate a satisfactory number of interested companies in the final design of the project.

*Halden* The time needed to carry out the project has slightly exceeded forecasts and the question of extending the period of joint operation, initially planned for three years, is now under study. The extension would be used to make fuller use of the experimental facilities afforded by the reactor and particularly its operation at full power with the second fuel charge.

*Dragon* Staff at this project at the UK Atomic Energy Authority's establishment at Winfrith Heath now number 140 of whom half are from Europe. The number will eventually increase to between 250-300. First tenders for the main reactor elements, the shielding, heat exchangers and other equipment, are to be invited.

## IAEA accepts equipment offer by the US

*Vienna* An offer of equipment valued at about £71,428 by the US Government has been accepted by the International Atomic Energy Agency. The equipment is intended for projects under the Agency's technical assistance programme.

**Technical assistance missions**

An IAEA preliminary technical assistance mission is to be sent to Greece, Morocco, Tunisia, Sudan, the Ivory Coast and the Federation of Mali to collect information and advise on atomic energy programmes in these countries. A further 20 nuclear experts are to be sent to Afghanistan, Austria, Brazil, Iran, Iraq, Korea, the Philippines, Turkey, Venezuela and Yugoslavia. In addition, Austria, Iraq, the Philippines and Yugoslavia will receive some equipment needed in connexion with the work of these experts.

**Health and safety measures**

A series of measures to protect health and ensure safety in atomic energy operations assisted by the IAEA has been passed by the Agency's Board of Governors. The main provisions are that the state assisted by the IAEA will submit a list of radiation exposures of people in excess of safety standards applied and a statement of the types, amounts and mode of radioactive waste disposals and release of radioactive materials.

**Middle East isotope centre**

A proposal for the establishment of a regional radioisotope centre in Cairo for the Arab countries is being considered by the IAEA. A final decision will be made after a fact-finding mission in the Middle East has published its findings.

• The striking photograph of EDF 2 on our last month's cover was taken by M. Decker of Saumur, who also took the ones of Chinon appearing in the text.

## French heavy water reactor plans

*Paris* Work is to go ahead this year on the building of France's first heavy water gas-cooled power reactor, EL 4. This is to be built at Morlaix in Brittany according to reports here. The decision taken means that French producers and processors of raw nuclear materials will have to step up their plans to take in this new development.

## The 'Six' hold talks on nuclear propulsion

*Brussels* Euratom experts from the six member countries discussed legal problems involved in the development of nuclear merchant shipping at a recent conference here. The general aim of the talks was to enable members to coordinate the position they will adopt at the London conference on the safeguarding of life at sea to be held from mid-May to mid-June. The conference is said to be the beginning of a programme of co-operation aimed at drawing up a framework of laws on nuclear merchant shipping.

**IAEA LABORATORY** Mr. Julius Raab, the Austrian Federal Chancellor, greets the International Atomic Energy Agency's President, Mr. Sterling Cole, while visiting the Agency's laboratory being built at Seibersdorf, Vienna

# OVERSEAS

## Oak Ridge investigates accident

*Oak Ridge* Further tests are being carried out by the USAEC's Oak Ridge National Laboratory on an employee who was overexposed to beta radiations during routine work.

The incident took place during normal cleaning of a cell in which cerium-144 and praseodymium-144 had been handled. The employee worked under a time limit designed to limit his exposure. A later survey of the cell showed that the radiation levels under which this time limit was based were greater than initially surveyed because some water which had collected in a trench and had provided some shielding, had drained away by the time the employee entered.

The exposure is estimated as 80 rads to body skin and 100 rads to face skin. The permissible occupational exposure for the skin is 6 rads per 13 weeks. Exposure to the lens of the employee's eyes is estimated at 5 rads compared to limits of 3 rads in 13 weeks.

• **Ghana** The International Atomic Energy Agency has recommended Ghana's application for membership for General Conference approval at its September meeting.

• **United States** The USAEC is to hold a symposium on non-destructive testing of reactor materials in Germantown, Maryland, on May 20.

• **USSR** The USSR is to import a hormone containing 5 mc of C-14 for the Academy of Medical Sciences, Moscow, from New England Nuclear Corporation.

• **United States** US uranium ore reserves were estimated at 86,100,000 tons on December 31, 1959. Uranium ore receipts in the last six months of 1959 were about 3,614,000 dry short tons.

## Russians discover new particle

*Moscow* Scientists at the High Energies Laboratory of the Joint Nuclear Research Institute at Dubna, near Moscow, have discovered a new nuclear particle—a positively charged anti-sigma-hyperon. It is said to be the first time a charged anti-hyperon has been observed. The discovery will add substantially to the scientific conception of the world of elementary particles.

The discovery of the new particle was preceded by extensive experimental work which involved the study of 40,000 pictures taken by means of a propane bubble chamber bombarded in a synchrophasotron.

According to D. I. Blokhinstev, corresponding member of the USSR Academy of Sciences, the investigation of the new particle will enable physicists to advance towards forming a comprehensive theory of elementary particles, to learn their structure and the laws of their mutual transformations.

## Australian research on power from the sun

*Canberra* Australian scientists are to conduct a series of investigations of the sun as a source of energy. The Physics Division of the Commonwealth Scientific and Industrial Research Organization is to use a specially designed light filter containing nearly 100 optical components in its work.

This instrument, which took more than five years to perfect, is expected to produce the world's first precise data on the velocity and temperatures of hydrogen gas on the surface of the sun. It could also yield new evidence about the intense magnetic fields of sunspots and make possible the first photographs of the sun's rotation.

## Michigan Boiling Water Reactor safety report

*Washington* A favourable report on the safety aspects of the boiling water power reactor that Consumers Power Company of Michigan proposes building on upper Lake Michigan has been submitted by the Advisory Committee on Reactor Safeguards to the US Atomic Energy Commission.

Consumers Power Company proposes to conduct a four and a half year research programme sponsored by the AEC, on its single-cycle forced circulation boiling water type reactor of 156 MW thermal. They intend to explore the areas of high power densities, optimum conditions for higher power density operation, longer fuel life and reduced fuel fabrication costs. It is anticipated that a power level of 240 MW thermal may eventually be obtained.

The Advisory Committee says that detailed design and the experimental programme will require additional study later but it is their opinion that a boiling water reactor of this type and power levels can be built without undue risk.

**RESEARCH CENTRE FOR PAKISTAN**

Mr. Morehead Patterson, left, American Machine & Foundry Company board chairman, and Dr. I. H. Usmani chairman of the Pakistan Atomic Energy Commission, discuss plans for a nuclear research centre in Pakistan

## Direct cycle boiling water reactor is US choice

*Washington* The direct-cycle boiling water reactor used in tankers is most likely to approach and achieve competitive power in the near future states a report sponsored by the US Atomic Energy Commission. Three reactors were studied, the direct and indirect-cycle boiling water reactors and the pressurized water reactor.

The direct cycle BWR had the lowest capital cost, the report adds. However, the cost of the simplified single-loop PWR was only slightly greater but the direct cycle BWR, because of its lower capital and operating costs and also because of its greater future potential, was the most likely system to achieve competitive power in the near future. The PWR would be the second choice because of reasonable capital costs and its very desirable, simple operating characteristics. The indirect-cycle BWR, while having some desirable features, would be the third choice.

The choice of the direct-cycle BWR for use in a tanker of 43,000 tons was further supported because it would most probably show a fuel and capital cost advantage in larger and/or multiple plants for other maritime applications.

## American nuclear rocket engine developments

*Washington* Two reactors will be tested this summer at Nevada under the joint Atomic Energy Commission-National Aeronautics and Space Administration programme to develop a nuclear rocket engine. They will be Kiwi-A Prime and Kiwi-A 3 which are nearly identical to each other.

Assembly of the Kiwi-A Prime reactor is now in progress and it will undergo cold critical tests before being moved to Nevada. Power operations should begin by the middle of summer. Shortly after these tests have been completed, tests on the Kiwi-A 3 reactor will begin. These latter tests will include endurance testing until there is positive evidence of damage to the reactor. After power runs have been completed, each reactor will be disassembled and examined.

The initial part of the joint programme—the demonstration of the feasibility of nuclear rockets by the ground operation of an experimental engine—is being conducted under the management of the Atomic Energy Commission.

• **USSR** A nuclear power section with working electric models showing chain reactions and reactor processes has been opened at Moscow's Polytechnical Museum.

## Isotope production at Trombay

*Bombay* Dr. Homi Bhabha has commented on the work the Trombay reactor will carry out in the production of radioisotopes. He said that when the reactor went into operation, India would be able to meet all her internal requirements and also export radioisotopes to other countries.

## Intense ion source development contract

*New York* A development contract for the construction of an intense ion source for acceleration and injection of hydrogen ions into the DCX thermonuclear machine at Oak Ridge National Laboratory has been awarded to High Voltage Engineering Corporation, Massachusetts. A prototype will be delivered to Oak Ridge for tests this year. High Voltage officials say the source will be capable of producing over 25 milliamperes of mass-analysed singly-ionized molecular hydrogen. It is expected to be the prototype for even more powerful sources operating in the 100 mA range.

The intense analysed beam will be accelerated to 600 keV by the Oak Ridge injector, and will then enter the DCX fusion device on which scientists hope to attain the millions of degrees of temperature required for a controlled thermonuclear reaction.

## US delegation ends Indian tour

*New Delhi* Talks on the possibilities of further cooperation between the United States and India on the development of the Indian nuclear power programme were recently concluded by the US Atomic Energy Commission delegation which went out to India at the beginning of March. The delegation went on a fact-finding tour to acquaint itself with the background to developing a major nuclear programme in India.

## US controlled reaction claim

*Washington* The latest controlled thermonuclear reaction claim has been made before the Joint US Congressional Committee on Atomic Energy by Dr. James Tuck, a British-born scientist. A reaction lasting nine-tenths of a millionth of a second and reaching a temperature of 13 million degrees had been produced in a research 'pinch' device at Los Alamos Scientific Laboratory. The device, Scylla II, uses a magnetic field to squeeze a plasma or ionized gas, in a tube 30 inches long and two inches in diameter.

## World radiation sign ?

*New York* A radiation symbol to signify actual or potential presence of ionizing radiation and to identify objects which emit ionizing radiation has been approved and submitted by the Atomic Industrial Forum for consideration at the next meeting of the International Organization for Standardization in Geneva. It is hoped that the symbol, a three-bladed device and a centre disk of reddish-purple on a yellow background, will be accepted internationally.

## US reactor goes critical

*Oak Ridge* A new reactor at the 'Tower Shielding Facility' of the USAEC's Oak Ridge National Laboratory went critical recently. It is designed to operate at power levels up to 5000 kWt and will be used to study atmospheric scattering of radiation in connexion with the US aircraft nuclear propulsion programme and for experiments on the shielding of materials.

**SPACE REACTOR**—The compact 220 lb atomic reactor to operate continuously and unattended in space for a year is examined by an engineer at Atomics International, a division of North American Aviation, Inc. It produces 50,000 watts of heat for the generation of electricity. The core of the reactor is in the cylindrical container (centre)

• **United States** The AEC has invited comment on a proposed regulation to guard against accidental criticality, radiation exposure to individuals and the release of fission products during shipment of irradiated fuel elements.

• **South Africa** Japan may become a purchaser of South African uranium according to a recent statement by the South African Secretary for Commerce and Industries.

• **United States** A US Congress committee has turned down a request for money to build a linear accelerator at Stanford University. Instead it has granted money for design studies only.

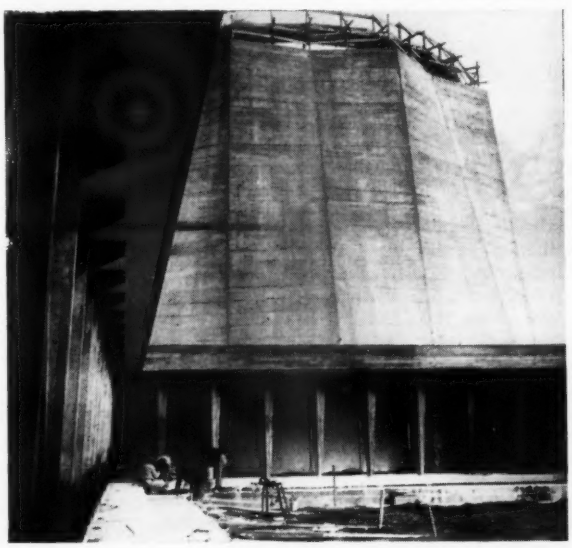
• **New Zealand** Nuclear research equipment worth £110,000 is to be supplied to New Zealand by the United States. It is expected to be installed at the Universities of Auckland and Canterbury and the New Zealand Institute of Nuclear Sciences by the end of 1960.

## Polish plans delayed

*Warsaw* Polish plans to build their first nuclear power station have now been postponed until 1968-70. The original plan was to build the plant between 1958-65. The decision was taken at a joint meeting of the State Council for the Peaceful Use of Nuclear Energy and a committee of the Polish Academy of Sciences.

## Puerto Rican reactor hearing

*Washington* Safety aspects of the boiling water reactor to be built near Rincon, Puerto Rico, were considered at a public hearing in April. The reactor will use uranium dioxide as fuel and produce nuclear superheated steam within the reactor core to generate 16,300 kWe. It is part of the AEC's Power Demonstration Reactor Programme and will cost about £6,980,000. The General Nuclear Engineering Corporation of Florida has contracted for the final design of the reactor. Construction is expected to be completed late in 1962.



**ISRAEL'S REACTOR**

Construction work in progress on Israel's reactor being built at Neve Rubin, near Tel Aviv. It is expected to be in operation by the middle of this year

## Worldview

### US portable reactor tested

*Washington* Critical tests of a portable reactor which can be carried by air in 16 units are now under way, says an announcement by the Martin Company. The reactor, the PM-1, will provide 1000 kW of electricity suitable for use by radar installations as well as seven million Btu's per hour of steam heat for buildings.

The walls of the reactor's tubular fuel elements contain a cermet of highly enriched uranium dioxide and stainless steel. The final design, which is awaiting approval by the USAEC, calls for 732 elements in the full core.

• **United States** A contract to develop a series of computational codes for small pressurized water reactors has been received by the Martin Company from the AEC.

• **South Africa** Exports of materials prescribed under the South African Atomic Energy Act fell in January–February this year to £7,990,000 against £8,600,000 in the similar period in 1959.

• **United States** By 1970, the US will be able to place into orbit a 60,000 kW nuclear powered generating system says Mr. J. W. Simpson, vice-president, Westinghouse Electric Corporation.

**SODIUM-GRAPHITE CRITICAL ASSEMBLY**

Engineers of Atomics International, a division of North American Aviation, Inc. inspect control and safety rods of a sodium-graphite reactor critical facility operating at the company's laboratory near Los Angeles. Nineteen fuel elements were used to start-up the eight feet by twelve feet assembly

## Proposals for Canadian Nuclear Association

*Toronto* A Canadian Nuclear Association may be established if enough interest is shown in a preliminary letter sent to several hundred organizations in Canada by the proposed Association's steering committee. The committee feels that as there will be a substantial nuclear industry in Canada in the near future, a definite needs exists for an Association to coordinate all related interests.

Among the objectives suggested for the Association is that it promotes and fosters conditions favourable to the healthy growth of the use of nuclear energy and radioisotopes and stimulates cooperation with other associations having similar purposes. Chairman of the steering committee is Mr. J. L. Olsen of the Canadian General Electric Company Ltd.

### Indo-Danish cooperation

*New Delhi* Further inter-governmental cooperation in the peaceful use of atomic energy is to come with the announcement that Denmark and India are to collaborate in this field. Mr. Nehru, the Indian Prime Minister, said in the Indian House of Parliament, that Professor Niels Bohr had invited Dr. Homi Bhabha, chairman of the Indian Atomic Energy Commission, to visit Denmark to discuss the matter.

The cooperation envisaged was mostly exchanges of materials and scientists and probably joint projects. There was no suggestion yet of any specific project being carried out by both countries, Mr. Nehru said.

### Yugoslavia to buy US reactors

*Belgrade* Following the visit of a delegation of Yugoslav nuclear energy officials to the United States, it has been announced that Yugoslavia is to buy a 100 kW research reactor from the US and two smaller reactors for university studies.

The supply of the reactor and nuclear fuel would be carried out through the International Atomic Energy Agency. Yugoslavia also hopes to buy US laboratory equipment and to send scientists and technicians to the States for training.

Meanwhile, the US State Department announced that both countries had reached an understanding on closer cooperation in the field of nuclear energy.

### Bids for Spert IV invited

*Idaho Falls* Bids for the construction of the US Atomic Energy Commission's Special Power Excursion Reactor Test No. 4 (Spert IV) have been opened. The estimated cost range of the work is £464,285. Spert IV will be a large pool-type experimental facility for the performance of basic reactor studies with various types of nuclear reactor cores.

Meanwhile, the USAEC announced that Spert II, used for studying nuclear reactor safety, has achieved criticality. The reactor is fuelled with highly-enriched uranium. Positions are provided in the reactor grid for 96 fuel assemblies, including the fuel sections of the control rods. Spert II is one of a series of reactors developed for the USAEC as part of a programme to find basic explanations for reactor behaviour under runaway conditions.

### S. Africa research reactor

*Pretoria* Dr. D. J. A. Roux, research director, South African Atomic Energy Board, is to visit Europe, the UK, and America to discuss buying a research reactor. Steps to speed-up the reactor construction at the Pelindaba site recently acquired by the Board have been taken.

• **Czechoslovakia** Plans are being made to put a 15 MW nuclear power station in operation by 1966.

### Queensland power reactor likely soon

*Canberra* A nuclear power station is likely to be installed in North Queensland by about 1970 says the Australian Atomic Energy Commission in a report to Parliament. The Mount Isa Mining Company, which has asked the Commission for their views on the operation of such a plant, is considered likely to be the first organization to operate a nuclear power plant in Australia. It is understood that because of conventional fuel costs, the installation of a reactor in North Queensland should be more economic than in other parts of Australia.

### Strontium-90 generator

*Washington* Martin's Nuclear Division has designed a 5 W generator with no moving parts, the heat source of which is strontium-90 locked safely within a stable, insoluble compound at the core of the device. The containment vessel, which is 8 ft high × 32 in. diameter, will house a smaller cylinder containing about 1 lb of the radioactive source. Surrounding the fuel capsule are 72 thermocouples which turn the heat directly into electrical energy to be used automatically for at least two years by weather measuring instruments and a radio transmitter.

As well as temperature and xenon effects the control system itself contributes to reactor instability

# The instability problem in gas-cooled reactors

*by* A. FONDA, B.Sc., Ph.D., A.Inst.P.,
*Research and Development Department, CEGB*

IN AN ARTICLE PUBLISHED in a previous issue of NUCLEAR POWER, Tyror (*1*) presented a detailed analysis of the sources and consequences of neutron flux instabilities in an uncontrolled CEGB-type nuclear reactor. Values were produced of the dominant time constants associated with the most significant flux harmonics, and indications were given of the nature of additional work required to design a suitable control system. In the ensuing period, further calculations on instability and control have been made by the UKAEA, the industrial consortia and the CEGB. A review article by Vaughan (*2*) has appeared recently, and a specific study has been reported by Carstairs and Taylor (*3*) in which the computations were performed by means of a large analogue computer.

## Necessity for mathematical studies

Within the next two years it is expected that the first two CEGB nuclear reactors will become operational. After an initial commissioning period, the responsibility for reactor operation will rest entirely on CEGB whose duty it will be to run these stations in the most economic manner subject to requirements of safety. In their role as operators, CEGB will be confronted with problems previously encountered only by the UKAEA in their power reactors. Although the design of these CEGB reactors is based primarily on the UKAEA Calder type, the operational requirements differ in several important basic details. Firstly, as a commercial enterprise, CEGB will be concerned essentially in producing electric power in the most economic manner. To minimize shut-downs, the replacement of fuel elements will be carried out at full load, which introduces new and complicated operational problems. Secondly, in non-steady or kinetic conditions, the Calder reactor is not a valid prototype of the CEGB reactors, as it is in the equilibrium state. The main differences are in the physical dimensions of the reactor, the power density and the irradiation level of the fuel. These three factors all tend to make CEGB reactors less stable kinetically than those of the UKAEA. This has already led, as indicated in the previous article (*1*), to the consideration of a sector control system to counteract undesired spatial variations in reactor quantities. It is a fairly obvious extension to consider automatic operation of these control rods, a novel feature in such reactors.

In the absence of a valid experimental prototype for nuclear reactor kinetics, it becomes essential for some form of mathematical study, or preferably simulation, to be adopted. This has become feasible with the introduction of high calibre computers. The advantages of such simulation are that it can be relatively fast, inexpensive and flexible, and that the system can be studied in conditions beyond those allowable in practice. This last point is particularly important since the first CEGB reactors are to be normally run fairly close to their design limitations on material temperature and no wide variations would be tolerable on an experimental simulator. The detail of accuracy of the simulation may vary from problem to problem and is governed mainly by the limitations of the computer.

**OUTLINE**

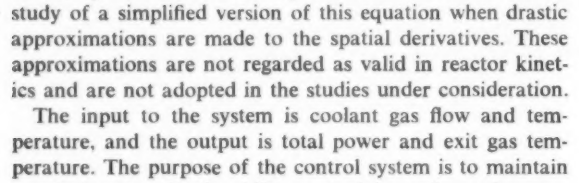
Investigations of the **controlled** reactor system have shown that there is a third source of instability as well as the two intrinsic to the uncontrolled reactor. This instability arises through the choice of inappropriate control parameters and results in the control system forcing the system as a whole into a divergent response. The time constant of this kind of instability depends on the choice of control system parameters and can be as low as a few minutes. Fortunately there are fairly wide ranges of parameter values which give a stable response.

## Nuclear reactor equations

In concise terms, these comprise a set of simultaneous partial differential equations linking neutron flux, material temperatures, nuclear concentrations and control rod positions. *Reactivity* is the most important term in the system and is a measure of the net neutron balance at any point. By elimination of other system variables, the neutron flux equation can be expressed as a complicated single partial differential equation, which is characteristic

of the system. Neutron, or *point*, kinetics result from a study of a simplified version of this equation when drastic approximations are made to the spatial derivatives. These approximations are not regarded as valid in reactor kinetics and are not adopted in the studies under consideration.

The input to the system is coolant gas flow and temperature, and the output is total power and exit gas temperature. The purpose of the control system is to maintain nominal output levels whilst constraining values of system



The IBM 709 Electronic Data Processing System can store the equivalent of over 327,000 decimal digits and has been used by the AEA for instability investigations (Fig. 1)

variables within specified limits. Disturbances to the system can enter through inlet or outlet variables or can arise within the system. The most significant disturbances under consideration are those which manifest themselves through the reactivity term.

The conventional theoretical formulation makes a number of simplifying approximations, concerned with the spectrum of neutron energies, the representation of control rod effects, the presence of the reflector, and non-linearities in, and spatial variations of, parameters. With the advent of more powerful computers, it is to be expected that some of these approximations will be discarded eventually.

## Kinetic response and instability

If the behaviour of a physical system can be represented mathematically by a set of simultaneous *ordinary* differential equations in time, the kinetic response of each system variable to a specific input disturbance is its subsequent variation in time. The kinetic response is therefore the complete solution in time. Due to the couplings between individual equations of the set, all system variables will eventually exhibit, in general, the same type of response apart from time lags.

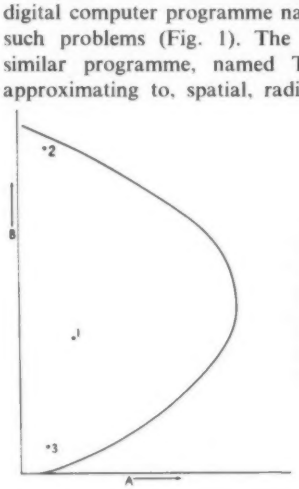
Instability or stability are special features of the kinetic response and are associated with its ultimate trend. Instability exists if the response diverges eventually, in either increasing or decreasing sense. Provided that the disturbance is itself not divergent, instability is an inherent property of the system. If the system is linear in all its variables, instability is independent of the initial state of the system; if it is non-linear in any variable, instability depends on the initial value of that variable. Analysis of instability of linear systems with constant parameters is essentially simpler than investigation of kinetic response. Standard algebraic methods exist, such as Routh's test, which provide a necessary and sufficient criterion. Other standard algebraic methods enable time constants to be determined as roots of a polynomial. It should be emphasized that the analysis of instability and determination of time constants give no direct information on the magnitudes of excursion of system variables.

Unfortunately, a practical nuclear reactor cannot be described realistically by a set of *ordinary* differential equations in time. In the simplest representation of the system two spatial derivatives must be introduced: one referring to the neutron flux leakage and the other to convective heat flow in the coolant stream. The effect of boundary conditions on the flux is to select a series of permissible flux shapes within the geometry of the reactor. These shapes are known as *reactor* eigen-functions or *modes*, each of which is associated with a specific spatial distribution of reactivity. The larger the physical dimensions of the reactor, the smaller are differences in reactivity levels between modes and hence the easier it is to excite higher modes through disturbances in reactivity.

Since the nuclear reactor system, with or without a control system, is described by a set of simultaneous *partial* differential equations, the determination of instability or of kinetic response is rendered vastly more complicated than in the case of ordinary differential equations. Physically, the difference is that between the behaviour of a fluid and of a rigid body, respectively. It can be shown that a single partial differential equation in space and time can be replaced by an infinite set of coupled ordinary differential equations in time. This replacement may be achieved either by expansion in modes or by spatial finite difference methods. Exact analytical solutions appear to be impracticable due mainly to the very awkward non-linearities produced by the reactivity term.

## Methods of solution of reactor equations

Spatial finite difference approximations enable a kinetic response to be obtained at every mesh point of every reactor variable. A representation of moving control rods can be incorporated without undue difficulty. However, since approximately fifteen reactor variables and at least 1000 spatial points should be considered, the size of the problem is enormous. In practice, a very high calibre digital computer must be used for solution, in which case a finite difference approximation in the time direction also is required. The UKAEA have produced an IBM704/9 digital computer programme named STAB, for solution of such problems (Fig. 1). The CEGB have a somewhat similar programme, named THIRST. By ignoring, or approximating to, spatial, radial or azimuthal directions,




The abscissa A represents the gain of the error signal and the ordinate B refers to the gain of its time derivative; a linear combination of these signals is used to drive the control rods. The response is stable within the boundary and unstable outside (Fig. 2)

considerable reduction can be made in the size of the kinetic problem so that it becomes amenable to solution by smaller electronic computers, digital and analogue. Finite difference methods can be used also to analyse instabilities.

The *modal* approach has been used both in instability and kinetic studies (*1, 2, 3*). Due to the fact that the reactivity term is a function of position in the reactor, the precise form of these modes is dependent on the detailed spatial distribution of control rods and stationary absorbers required to achieve exact criticality of the system. Since there exists in principle an infinite number of alternative distributions of rods and absorbers there is a corresponding ambiguity in the specification of a mode. It is simpler to represent these modes in terms of *harmonics*, which are *geometrical* eigen-functions and are associated with purely *uniform* reactivities (*1*). It is assumed that any mode can be expressed as a particular linear combination of harmonics, although the validity of the assumption remains to be rigorously proved in view of the non-linearity of the flux equation. It is further assumed that, under kinetic conditions, such a linear combination, with time-varying components, remains a valid description of the flux. Provided that the input disturbance to the system is small, only a relatively small number of harmonics is required to secure convergence. A rigorous proof has not been given that the converged solution is in fact the correct solution, although this appears likely. An analogous point in quantum mechanical theory is discussed by Mott and Massey (*4*).

Before the use of electronic computers, control had been represented in terms of perfect constraints applied successively to different harmonics; leading to an underestimate of the effects of inherent couplings between modes. More recent studies, in kinetics and instability, have used more realistic descriptions of control systems and have taken account of the spatial disposition of rods and their maximum velocities, the nature and arrangement of error signal monitors and of the effect due to various initial flux shapes.

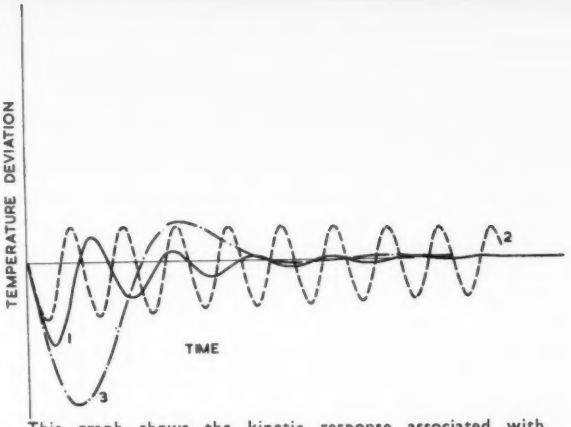
## CEGB control system studies

A series of studies is in progress on a large analogue computer with the object of optimizing control system performance. Investigation is being made of the initial transients following a disturbance and of the longer term response which is influenced by intrinsic instabilities. Figs. 2 and 3 show qualitatively typical results related to the control of the initial response. The response refers to a material temperature at a particular point in the reactor.

These present analogue computer studies, unlike those on the IBM 704/9 computers, are restricted to a purely axial reactor representation.

## Accuracy of results

There are two major sources of error in these calculations. The first is the inaccuracy of the theoretical representation of the reactor and the second is in the method of solution. Progress has been achieved in the latter through the use of faster and larger computers. However, similar progress has not been made in checking the formulation errors. In general, the standard of formulation in kinetic problems is, due to their complexity, considerably below that used in equilibrium studies. Until experimental results become available from the first CEGB reactors, the only means of assessing the accuracy of these calculations is by using experimental results from UKAEA reactors.




This graph shows the kinetic response associated with three different control settings corresponding to three points selected in Fig. 2 (Fig. 3)

## The nature of flux instabilities

A clear understanding of the nature of these effects is essential to the efficient operation of CEGB power reactors. In the absence of a suitable analogy, it is helpful conceptually to be able to distinguish between space and time variations. This can be achieved by visualizing the flux as a combination of three-dimensional spatial harmonics (*1*) whose amplitudes are functions of time. In the initial steady state, all coefficients are constant and only the first few are significant. The relative magnitudes of these constant coefficients can be determined by standard harmonic analysis of the steady state flux distribution. Localized variations in reactivity tend to produce associated fluctuations in the flux distribution which lead to increased components of higher harmonics.

A specific disturbance will at first excite certain harmonics predominantly, but due to the reactivity couplings between them, other harmonics will be progressively stimulated until, ultimately, all harmonics in general respond in the same manner, apart from time lags. Thus the dominant time constants quoted for the lowest harmonics (*1*) will be increasingly modified in time and will eventually coincide. Instabilities due essentially to the reactivity are directly related to the sign of harmonic couplings. A coupling may be defined as the complete spatial integral of the reactivity multiplied by the product of the associated harmonics. Diagonal, or self, couplings are generally relatively large. Other couplings customarily considered are those between the first and a higher harmonic. The remaining non-diagonal couplings are often ignored in theoretical studies.

In certain conditions, particular harmonics will be absent throughout the response. For example if there is axial symmetry in the initial flux distribution, in the initial disturbance and in the control action, no azimuthal harmonics can be generated. However in the general case, where operational limitations apply, the presence of all harmonics should be considered. A distinction may be drawn between *direct* and *indirect* harmonic excitation or suppression. Direct stimulation involves only those effects resulting from changes in amplitude of that particular harmonic, whereas indirect stimulation is induced by interaction with other harmonics.

The presence of a practical control system introduces additional important harmonic couplings. These are sensi-

tive to the precise nature of the control system. From the analytical aspect, the simplest system would be a material, associated with each fuel element, which possessed a large negative coefficient of reactivity and prompt response to changes in flux or temperature. Such a system could in principle eliminate completely instabilities associated with neutron temperature and xenon-135 poison. Since control is in fact exerted through moving rods actuated by certain error signals its effect is more complicated and less stabilizing than in the hypothetical situation described. In particular, if the control system acts uniformly on a total power signal, it is unable directly to stabilize azimuthal harmonics and is indeed unable to detect their presence which may produce excessive material temperatures in localized regions. This is the main reason for controlling azimuthal harmonics sectorwise.

Current philosophy on control of spatial harmonics is that it is not necessary to set every individual control rod on independent automatic control. The implication is that high harmonics, if present, will be controlled indirectly or by manual operation. Consideration of the *time scale* of events shows that the control system must be designed to act efficiently in three regimes during the course of a kinetic response. It must, firstly, optimize the stability of the initial transient which may involve several harmonics. Secondly, after a period of about fifteen minutes when instability first manifests itself in the fundamental harmonic, it must prevent any divergence in total power and minimize destabilizing effects on higher harmonics. Finally, it must counteract local temperature deviations due to instabilities appearing subsequently in these higher harmonics. It is obvious that the efficient design of such a control system, involving both direct and indirect action, must take adequate account of reactivity distribution and harmonic couplings and is indicative of the use of a large scale computer.

## Design and operational implications

The design of nuclear reactors, in common with that of most equipment, is optimized for normal steady operation. In practice, of course, this detailed specification changes continuously throughout the life of a reactor. However, the alteration is so gradual that only small adjustments are necessary to maintain nominal output under conditions of pseudo-equilibrium. On the other hand, the design of the control equipment and confirmation of safety trip dispositions requires consideration of non-equilibrium conditions. In particular, the philosophy of normal manual control by bulk rods should be compared with that of automatic control by a few sector rods, or possibly normal automatic control by many rods. Apart from the question of reliability, the main disadvantage of fully automatic control exerted from the top of the reactor, and actuated by outlet gas temperature deviations, appears to be in its dubious performance with regard to axial stability. This, of course, applies equally to manual bulk control. The situation could be improved by use of an alternative error signal for control purposes, which illustrates the fact that control system performance is strongly dependent on the choice of actuating signal.

From the operational point of view, non-equilibrium conditions are as significant as the steady state, and the design which is satisfactory at equilibrium may be less so in unsteady conditions. One of the practical applications of theoretical kinetic studies is in the evaluation of the operational merit of nuclear reactors. This type of information is important in assessment of the feasibility of automatic control and optimization of the CEGB system. It is essential to know what variations in flux shape can occur and their effects on stability and temperature excursions, to understand which type of disturbance tends to produce a particular type of spatial distortion and to know whether the automatic control rods can cope with this situation and in what period of time. It is also necessary to be assured that maximum permissible fuel can temperatures are not exceeded even though detailed practical measurements may not be available. In this respect, theoretical kinetic studies can be useful since they can predict detailed temperature distributions during the course of a particular response. In fact, the automatic control system parameters may be optimized for minimum can temperature excursions, even though control is actuated by coolant outlet temperature deviations.

## Future studies

The above discussion has been restricted essentially to the behaviour of the reactor following small disturbances about its normal equilibrium state. Such disturbances should be regarded as inherent and, in their least serious form, may be termed reactor noise. From the design aspect, there are numerous other cases of interest where a knowledge of the kinetic response and its controllability is required. In particular, the optimization of safety trips requires such attention. From the operational point of view, there are also numerous problems not covered by the above considerations. To clarify these practical requirements, programmes of calculation have been undertaken which deal with specific disturbances and fault conditions.

Eventually, of course, as increasing numbers of nuclear power stations come into operation and replace conventional stations, the normal state of nuclear reactors will no longer be that of nominal full power. Variable power demands will be imposed so that a degree of flexibility will be required operationally. In these circumstances, if nuclear power is to be economically competitive, the design of these stations will require to be optimized for a relatively wide variation in parameters, and, similarly, operational ease will be necessary over a wide working range. Under these conditions, the present limitations on material temperatures should be relaxed and it is partly to this end that more advanced types of nuclear reactor are now being actively considered.

The shut-down of nuclear reactors is an action involving heavy economic penalties due mainly to the delayed effect of fission products. It seems reasonable to expect that, in future, the use of trips for shut-down will be reduced to a minimum and that the normal control system, possibly automatic, will be able to cope adequately with the majority of fault conditions in addition to counteracting the effects of small disturbances.

**Acknowledgments**

The author wishes to acknowledge helpful discussions with colleagues at CEGB, and to thank IBM for permission to use the photograph and Mr. A. Jebb for preparation of the figures.

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Only highly industrialized countries really want single power reactors in the 200–400MW range in the near future; the immediate need in under-developed countries is for low-power plant

# *Small power reactor survey*

*by* J. SPENCER BURKETT, FLA

*Assistant Editor, 'Nuclear Power'*

THERE ARE only three reactor types for 5–40 MWe nuclear power plant that can be seriously considered for construction at an early date to achieve reasonably economic power. These are the pressurized water reactor, the boiling water reactor, and the organic moderated reactor (*1*). This does not mean, however, that other types will not be developed in the future possessing attractive economic potential.

PRESSURIZED WATER REACTORS Heat is removed by light water without bulk boiling of the coolant but an operating pressure of up to 2000 lb/in²a is required. Use of water allows higher power density than having steam in the coolant channel. The strong negative moderator temperature coefficient of reactivity allows the system to follow minor load demand changes without external control. Steam pressure of around 600 lb/in²a saturated can be produced at an approximate 25% net efficiency.

BOILING WATER REACTORS Bulk boiling is allowed to occur and results in somewhat lower operating pressures within the core vessel than the PWR.

Although experience so far gained indicates reliable and safe operation, proper system design will no doubt overcome the control problem caused by effects of changes in steam demand on the void of the core. This reactor is capable of operating at the primary system pressure of 1000 lb/in² but higher operational pressures may be possible with development.

ORGANIC MODERATED REACTORS The use of an organic coolant allows higher primary system operating temperatures of 600–650°F without a high pressure primary containment system. The main problem to be overcome, however, is that of thermal and radiolytic decomposition.

*Gas-cooled reactors* The possibility of obtaining exit temperatures of 1000°F to generate high pressure steam makes this principle comparable to steam obtained in many modern power plants. Development for economic small reactor application is a long term aim, however, at the moment.

*Other reactor types* Advanced systems that have high-temperature potential but lack sufficient operational experience include the liquid metal fuel reactor, the molten-salt reactor, the thermal breeder aqueous homogeneous reactor and sodium cooled systems.

> The demand for small nuclear power plants is likely to be centred in comparatively under - developed regions where difficult access to fuel and absence of a national grid has limited human activity and prevented industrial potential being developed. Reactors for these areas will have to be reliable and simple to operate because expert assistance will not normally be available. In such cases, where power is urgently required for mining, distillation of brackish water, irrigation pumping, metallurgical and isolated industrial plant, the need is sufficiently great to dictate the use of nuclear power generation even though the cost of power would be high by American or European standards. Even in the USA, the Rural Electrification Administration has shown a strong interest in such small reactors for outlying communities in high power cost areas.

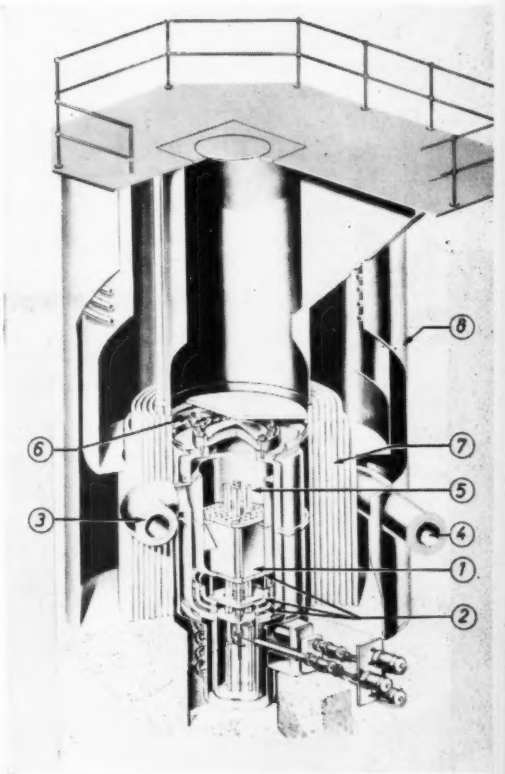
## US effort

The Americans have by far the greatest experience in the design and development of small power reactors. Apart from experience gained in operating pressurized water reactors for submarines, a programme has been under way since 1955 for the development of compact, lightweight, power and heat reactors capable of being set up rapidly and at minimum costs at remote military installations. As early as December 1954, a £M0·7 contract was awarded to Alco Products for the design, construction and testing of the Army Package Power Reactor, APPR-1, now designated Stationary Medium Powerplant 1, SM-1.

SM-1 has incorporated the idea that significant mechanical rationalization of reactors of the PWR type could be achieved by eliminating the intermediate heat exchanger. Other design breakaways include the use of stainless steel rather than zirconium for

Alco's SM-1 Army Packaged Reactor.

1. Reactor
2. Thermal shield
3. Inlet
4. Outlet
5. Control rods
6. Fuel transfer tube
7. Iron-water shield
8. Primary shield tank



the fuel elements, and the employment of rod drives at the bottom of the reactor vessel. Burnable B-10 poison is incorporated in the fuel elements to balance fuel burnout as the reactor operates (*2*).

Up to the end of 1959, the plant had operated for 13·7 MW years of its expected 15 MW-year core life and had generated 23,188,000 kWh of electricity. The total cost estimate for power generation is 53·30 mills/kWh and, while this is not cheap power, it is about the same as that for the very much larger PWR. A further project, PM-2A, developed by Alco for full power operation by September 1960, calls for 1·5 MWe and $10^6$ Btu/h steam for heating but, unlike SM-1, it will have a condensing system using air and ethylene glycol. By eliminating concrete for shielding it will be possible to dismantle the plant into 20–30 skid mounted component packages with a total plant weight of 300 tons

The Portable Medium Powerplant-1, PM-1, is another small PWR, under development by the Martin Co. at a cost of £M2·1. It will produce 1 MWe together with 2 MW of spare heat for an operational air force station and will have a minimum operating life of two years. It is scheduled for operation by early 1962. The cylindrical core, 3 ft high × 23 in. dia., will be made up of 732 tubular elements containing a cermet of highly enriched $UO_2$ and stainless steel. The core will be charged with some 60 lb of U-235 of which more than one-third will be burnt during the core's two-year life. The reactor has been designed to permit local boiling enabling the system to operate with a smaller pump and piping.

The Army Reactor Programme also includes the development of boiling water reactors as portable and modularized plant for low power production. Stationary Low Power Reactor, SL-1, or the Argonne Low Power Reactor as it was previously called, is a prototype direct cycle BWR producing 300 kWe and 400 kW of space heating. The plant first operated at power in 1958 and in February 1959 it was transferred from ANL to Combustion Engineering.

Up to the end of 1959, SL-1 had operated for 1 MW year of its expected 6 MW-year core life, generating 806,100 kWh of electricity. Operation and plant evaluation has shown the suitability and feasibility of BWR field units and has indicated the increased potential of such plants with further development. A recently completed conceptual design based on SL-1 indicates that a portable plant could be built and installed at a remote site for around £M0·7 (*3*).

Also under the Army Programme is a project to develop a mobile gas-cooled power reactor that involves three stages, the whole programme to be operated by Aerojet-General. Gas-cooled Reactor Experiment, GCRE-I, which reached criticality in February will be used, together with GCRE-II, for testing various kinds of fuel elements and for developing engineering data and experience for the Mobile Low-Power Reactor, ML-I, a prototype power unit generating 400 kW to be readily transportable by land, sea and air. ML-1 which is scheduled for operation in May 1961 will be the first closed-cycle gas-turbine power plant to be operated from a nuclear reactor heat source. Pin type fuel elements, consisting of fully enriched $UO_2$ pellets clad in Hastelloy X, have a maximum fuel temperature of 2350°F.

A 15 MW gas-cooled closed-cycle reactor power system was the subject of a feasibility study for the Ford

## SMALL POWER REACTORS, USA

| | 1957<br>SM-1 (APPR-1)<br>PWR | 1958<br>SL-1 (ALPR)<br>Direct cycle<br>BWR | 1957<br>VBWR<br>Direct cycle<br>BWR | early 1961<br>Elk River<br>indirect cycle<br>BWR | USAEC Evaluation study—Small sized nuclear power plant. 1959<br>GNEC<br>BWR | <br>Alco<br>PWR | <br>AI<br>OMR | Oct. 1961<br>Piqua<br>OMR |
|---|---|---|---|---|---|---|---|---|
| OUTPUT | | | | | | | | |
| *Gross thermal* MW | 10 | 3 | 30 | 58·2<br>(14·8 super heat) | 47<br>24·7 (super heat) | 49·2 | 73 | 45·5 |
| *Net elec.* MW | 1·8 | 0·3 (0·4 heat) | 5 | 22 | 23·5 | 12·5 | 20 | 11·4 |
| CORE | | | | | | | | |
| *length (or height)* | 22 in. | 25·8 in. | 37 in. | 60 in. | 56·5 in. | 48 in. | 54 in. | 54 in. |
| *nominal dia.* | 22·2 in. | 34·5 in. | 36 in. | 56·9 in. | — | 48 in. | 60 in. | 60 in. |
| FUEL | | | | | | | | |
| *form* | plate | plate | plate | pellets | pellets | pin type | concentric tubes | concentric tubes |
| *composition* | $UO_2$-ss dispersion | U-Al | $UO_2$-ss dispersion | $ThO_2$-$UO_2$ | $UO_2$ | $UO_2$ | 3·5wt% Mo-U alloy | 3·5wt% Mo-U alloy |
| *enrichment* | high | high | fully | 93% | 1·7% | 4% | 1·7% | 1·8% |
| *canning* | ss 0·005 in. | Al 0·035 in. | ss 0·005 in. | ss | Zr-2 0·027 in. | ss | Al 0·035 in. | Al 0·035 in. |
| *total weight* | 22·5 kg U-235 | 350 g U-235 | 19·8 kg U-235 | 208 kg $UO_2$<br>4500 kg $ThO_2$ | 4255 kg | 3806 kg | 11,770 kg | 6870 kg |
| *av. thermal neutron flux* (n/cm²/s) | $2·7\times10^{13}$ | $7·5\times10^{12}$ | $2·8\times10^{13}$ | $1·55\times10^{13}$ | — | $1·4\times10^{13}$ | $1·4\times10^{13}$ | $1·4\times10^{13}$ |
| COOLANT | | | | | | | | |
| *max working pressure* (lb/in²g) | 1200 | 300 | 1000 | 1000 | 1450 | 1960 | 121 (inlet) | 106 (inlet) |
| *temp. in* | 431°F | | 100°F | 534°F | 430°F | 487°F | 552°F | 523°F |
| *temp. out* | 450°F | 420°F | 546°F | 537°F | 593°F | 517°F | 625°F | 575°F |
| PRESSURE VESSEL | | | | | | | | |
| *height* | 13·5 ft. | 14·5 ft. | 19·4 ft. | 25 ft. | — | 22 ft. 6 in. | 35 ft. 5 in. | 35 ft. 5 in |
| *o.d.* | 4 ft. | 4·5 ft. | 7 ft. | 7 ft. | 6·71 ft. | 5·4 ft. | 8·5 ft. | 8·5 ft. |
| *wall thickness* | 2·75 in. | 3/4 in. | 3·375 in. | 3·375 in. | 4·8 in. | 4·75 in. | 1·25 in. | 1·25 in. |
| *material* | carbon steel ss clad | carbon steel ss clad | carbon steel ss clad | carbon steel ss clad | carbon steel ss clad | carbon steel ss clad | carbon steel | carbon steel |
| *max. working pressure* (lb/in²g) | 1600 | 400 | 1215 | 1250 | 1650 | 2200 | 286 | 286 |
| *max. working temp.* | 650°F | 450°F | — | 650°F | — | — | 750°F | — |
| TURBINE | | | | | | | | |
| *inlet pressure* (lb/in²a) | 200 | — | 490 | — | 1265 | 375 | 800 | 455 |
| *inlet temp.* | 407°F | 420°F | 465°F | — | 1000°F | 444·6°F | 580°F | 457°F |

*Abbreviations*:—GNEC *General Nuclear Engineering Co.* AI *Atomics International.* VBWR *Vallecitos Boiling Water Reactor.* ss *stainless steel*

Instrument Co. (*4*) in 1956. The open cycle gas turbine was rejected largely on the grounds of radioactive contamination and the double-cycle system was rejected primarily due to increased metallurgical problems that might result from excessive amounts of radioactive leak through the heat exchanger.

The study considered a right cylinder core with 10% $UO_2$ enrichment, graphite moderated and nitrogen cooled. The operating pressure was 530 lb/in² with turbine inlet temperature at 1300°F. At a cost of 15·8 mills/kWh it was concluded that both technically and economically the system appeared feasible, but further research and development was required to establish a firm design.

The 30–40 MWe prototype High Temperature Gas-Cooled Reactor being constructed by Philadelphia Electric Co. and General Dynamics for completion by December 1963, will eventually yield data suitable for further small power reactor evaluation. The prototype will use combined fuel-moderator elements containing enriched uranium and thorium carbide fuel dispersed in a graphite matrix. A combination of large heat transfer surface and high temperature capability greatly reduces reactor size in relation to the output (*5*).

## Small-sized power plant programme

The most interesting development to date in USA has been the recent evaluation of reactor systems suitable for small-sized (5–40 MWe) nuclear power stations and for immediate construction in high cost fuel areas. Of the types examined, the advanced status of technology of the BWR, OMR, and PWR compared with other systems made these the only concepts worth considering. Selection was based on maximum assurance of long term operational reliability and for the early demonstration of accurate target costs. The construction cost set was £M4·6, double that for conventional plant; at a capacity factor of 60% the total generating cost for a first generation plant was estimated to be 16·9 mills/kWh. This compared with 10·9 mills for conventional plant (fuel, operation and maintenance charges 8·6 mills compared with 7·8 mills of the latter) (*6*).

An initial investigation of conventional power plants in this range led to the acceptance of 22 MW gross as the preferred size. Whilst it was agreed that present information did not lead to future economic competitiveness of small-sized nuclear power plants, by reason of this uncertainty it was necessary to construct one or more in order to develop a dependable yardstick for further comparison and determination.

On the question of cost none of the three plants appeared to possess an advantage. With the direct cycle BWR the assurance of attaining low overall generating costs with high thermal efficiency was doubtful because of lack of sufficient experience with fuel element defects and failures. Direct cycle superheat brought a corrosion problem with oxygenated steam and the possible operating difficulty in avoiding steam leaks and coupling two different heat sources.

The OMR concept was attractive because of excellent steam conditions associated with a low pressure primary loop and minimum contaminant. Demonstration was lacking, however, in metallic fuel element behaviour and the characteristics, life and behaviour and maximum limit of coolant operation. High safety factors and design contingencies due to lack of operating experience resulted, at the moment, in high capital costs.

A 22 MWe (gross) PWR system with slightly enriched $UO_2$ fuel with fossil fuel superheat was finally selected as the first project under the SSNPP programme. It had excellent load following characteristics and a reliability and simplicity of total plant operation not matched, at the moment, by any other competing system. In addition, publicly owned generating bodies were assured that the plant was operable upon demand without a long period of experimental start-up and without requirements of excessive down-time for equipment and replacement, modification or decontamination (*7*).

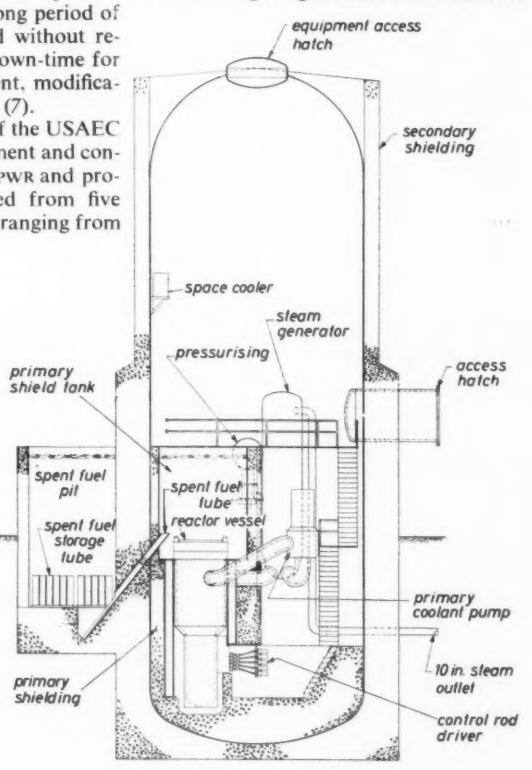
The 1960 programme of the USAEC now includes the development and construction of a 16·5 MWe PWR and proposals have been received from five public power groups, bids ranging from £M0·7–1·6 bringing the total cost of power plant to £M4·3–5·2. The AEC will build and own the reactor and the utility will provide plant site and turbogenerating facilities, buy steam and operate entire plant. The scheduled date for criticality is May 1962.

Another development reactor is the 16·3 MWe Boiling Nuclear Superheat Reactor, BONUS, to be built by General Nuclear Engineering for the AEC and Puerto Rico Water Resource Authority. Of the 50 MW thermal output, 13 will be provided in the superheater. Coolant inlet temperature will be 354°F, exit at 900°F, operating at 900 lb/in² a steam. The fuel will consist of zircaloy-clad $UO_2$ pellets at 1·85% enrichment. The design permits less nuclear sensitivity to flooding and voiding, high temperature and neutron economy.

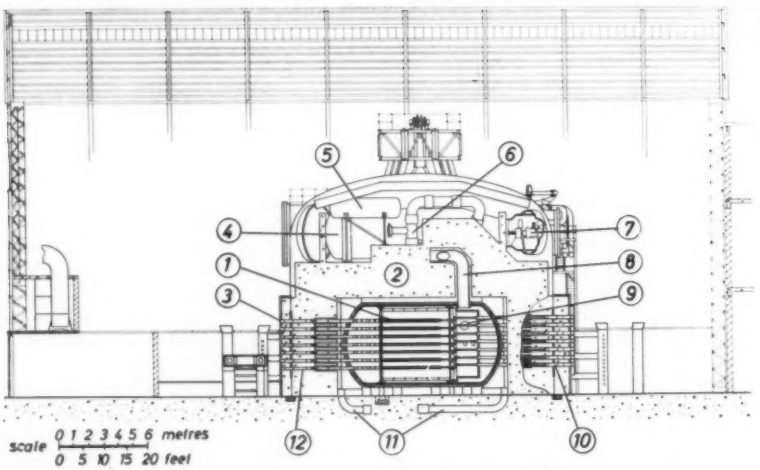
## Plans in the UK

Whilst no actual operating experience has been gained in small power reactors, a number of companies have designs available.

GEC of Erith see no reason why gas-cooled reactors should not be used in the 20–100 MWe range provided higher burn-up is achieved by fuel enrichment and higher temperatures attained by employing, say, uranium dioxide. In a preliminary 30 MW design, the whole of the station is under one roof; the primary circuit is contained within a gas-tight shell. Fuel elements




Alco's 12·5 MWe PWR design was selected for the 1960 SSNPP programme of USAEC. The vapour container shown here is a carbon steel pressure vessel with concrete radiation shield. Access is by way of side hatch for refuelling and maintenance. Top hatch permits removal and installation of reactor vessel, generator, primary pump, etc.




The GEC 30 MWe gas cooled design: 1 core; 2 biological shield; 3 charge face; 4 steam raising unit; 5 steam drum; 6 main gas valve; 7 gas circulator drive; 8 cold-gas duct; 9 hot-gas duct; 10 control rod standpipes; 11 shield cooling ducts; 12 charge standpipes

of the cross-flow type consists of $UO_2$ enriched to approximately 2·16% clad with stainless steel and supported in graphite sleeves. Carbon dioxide at 400 lb/in²g enters the reactor at 500°F and leaves at 1000°F. Steam from two steam-raising units, which are mounted above and parallel to the reactor vessel, is at 900°F with a pressure of 900 lb/in²g. Estimated cost based on British civil costs is nearly £M5·5 (£182/kW net), whilst total generating cost is about 16 mills/kWh.

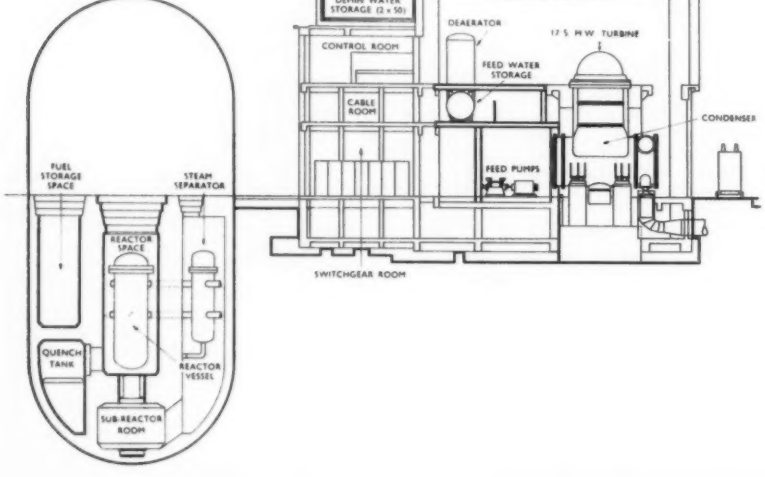
The Hawker Siddeley Nuclear Power Co., one of the five companies submitting tenders for the marine reactor, is in the market for land-based OMR stations. They have a 20 MW design using $UO_2$ fuel elements of 1·7% enrichment giving steam at the turbine stop valve of 600 lb/in²g at 615°F. The estimated cost of construction in this country is £M2·2 and working at 70% utilization generating costs would most likely be 10 mills/kWh.

Mitchell Engineering has been offering guaranteed-price nuclear power in the 17·5 MW range for over 12 months. This firm is associated with American Machine and Foundry of New York and General Nuclear Engineering for the design and construction of boiling water reactors in the range 17–75 MWe.

The latest design offered is a 30 MWe forced circulation direct cycle BWR using a 'reboiling' cycle producing saturated steam at a pressure of 1200 lb/in²a. Total electrical power costs in existing designs range from 12·74 mills/kWh for a 20 MWe plant to 9·57 mills for a 60 MWe. The 22-MWe design that was submitted to Cuba some time ago and is still being negotiated, although essentially identical to Elk River, uses $UO_2$ in stainless steel tubes and oil-fired superheater instead of coal fired. It was estimated that it would be only 0·4 mill short of competitive price at start-up in 1962 and by 1982 3 mills below conventional power.

In the PWR field is Babcock and Wilcox working in association with Humphreys and Glasgow for the installation of small power reactors in any part of the world.

Steam flow in Mitchell's 17·5 MWe BWR is 220,000 lb/h at 915 lb/in² a. It is returned to the reactor at 250–350°F after condensing and reheating stages




## Other countries

In Germany, the only small reactor power station under construction is the 15 MW BWR at Karlstein/Main. The reactor, which will have an average neutron flux of $2 \times 10^{13}$ and an initial core loading of 6410 g $UO_2$, has been designed by GEC of New York, working in association with Allgemeine Elektrizitätsgesellschaft.

Brown Boveri/Krupp have plans for a 15 MWe high temperature pebble bed reactor to be built at Julich at a cost of £M3·4, half of which is to be contributed by the Federal Government. The fuel will consist of 6-cm balls each contained in 3·5 g uranium enriched to 20%. The reactor coolant, a mixture of 22% helium and 78% neon, will enter the core at 200°C and leave at 850°C. Reactivity control is achieved by changing the number of balls in the core.

In Italy a 30 MWe OMR, planned as a joint government-industry project, is to be built by SORIN at a cost of £M3·5.

Whilst heavy water reactors have not yet been considered seriously for present generation small power reactors, a Swiss project in the 30 MW thermal range was put up by Sulzers for the production of electricity and space heating. The design was described at Geneva in 1958 (*8*).

Another Swiss Company, Energie Nucléaire S.A. of Lausanne has plans for building a 5 MWe experimental BWR power plant fuelled with uranium dioxide in pellet forms, zircaloy clad, and enriched to 1·75%. Average neutron flux is $1·1 \times 10^{13}$ and, operating at a pressure of 70 kg/cm² and a temperature of 285°C, it will enable a variety of BWR systems to be studied. Although optimized for direct cycle, it will permit experiments on dual and indirect cycles as well as on natural or forced circulation.

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Adapting standard methods of heat exchange design can cut down labour considerably

# Designing boilers for gas-cooled reactors

*by* B. G. EDISS, A.M.I.Mech.E., A.R.T.C.S.,
*Nuclear Power Plant Co. Ltd.*

THE DESIGN of the heat-exchangers or boilers for gas-cooled, graphite-moderated power reactors appears at first sight to present no particular problems if adequate data is available. Further examination, however, shows that some adaptation of standard methods of heat exchange design can considerably reduce the labour of computation. The design basis usually supplied consists of a thermal duty, and operating gas temperatures and pressure. The method of optimization used to determine the parameters of the usual dual pressure steam cycle associated with gas-cooled systems, are outside the scope of this article. Whilst the design of the boiler revolves around the steam conditions, they do not in themselves dictate the boiler design. Given steam conditions, however, boiler design may proceed.

The parameter which influences the boiler most nearly is the coolant gas pressure drop. Should the coolant gas pressure drop be incorrectly ascertained the boilers may well be too elongated or too rounded resulting in the penalizing, both technically and economically, of the power station design.

Following the accepted present practice, the boiler for a typical 650MW reactor would be designed to consist of a number of separate economizer, evaporator, and superheater sections, all accommodated in a single pressure shell, with the reactor coolant passing in cross flow over banks of tubes with the steam/water streams flowing inside these tubes.

The advantages of the use of extended surface tubing have always been appreciated in British practice, and a full comparison with bare tubes has been presented elsewhere, Ediss *et al.* (*1*). The extended surface tubing which will form the basis of this design is of the transverse finned type, and to proceed with the design it is necessary to select the proportions of a specific tube, and determine the heat transfer and pressure drop performance of the bank in which the tubes are arranged in a pattern largely determined by considerations of mechanical convenience.

Many attempts have been made to rationalize the behaviour of banks of finned tubes. Such rationalizations have been directed towards the determination of an equivalent diameter from the many numerical dimensions which must be specified to describe the bank completely. Although such attempts have some academic interest, they are very far from being sufficiently reliable or accurate for use in the design of large equipment items of vital importance.

For the purpose of this article, however, one of the published correlations has been selected, as this permits the investigation of the behaviour of a heat exchange matrix with variation of the arrangement of a given tube, Jameson (*2*).

$$h_o = 0{\cdot}0918.\ \frac{k}{D_e}\left[\frac{G\,D_e}{\mu}\right]^{0{\cdot}723} Pr^{\frac{1}{3}}$$

The correlation for pressure drop over extended surfaces is that proposed by Gunter (*3*).

$$\triangle P(\text{lb/in}^2/\text{row}) = \frac{2{\cdot}81\times10^{-13}\times\mu^{0{\cdot}145}\times G^{1{\cdot}855}\times S_v\times S_L{}^{0{\cdot}6}}{S\times D_v{}^{0{\cdot}745}\times S_T}$$

It is reasonable to expect, for any given geometry of extended surface tubing used in staggered formation, that, provided the velocity of gas in the diagonal pitch is equal to that in the transverse pitch, the area of heat transfer surface required will vary solely as $Re^n$. Thus a mechanism exists such that it is possible to move from pitch to pitch.

**TABLE 1** *Selection of a specific tube*

| | | |
|---|---|---|
| Outside dia. of fins | = | 2·786 in. |
| Root dia. of fins | = | 2·109 in. |
| Fin thickness | = | 0·062 in. |
| Number of fins/ft | = | 64 |
| Tube bore | = | 1·66 in. |

$$A_o = \frac{\pi 2{\cdot}109(0{\cdot}1875-0{\cdot}062)}{12\times0{\cdot}1875} = 0{\cdot}37\ \text{ft}^2/\text{ft}$$

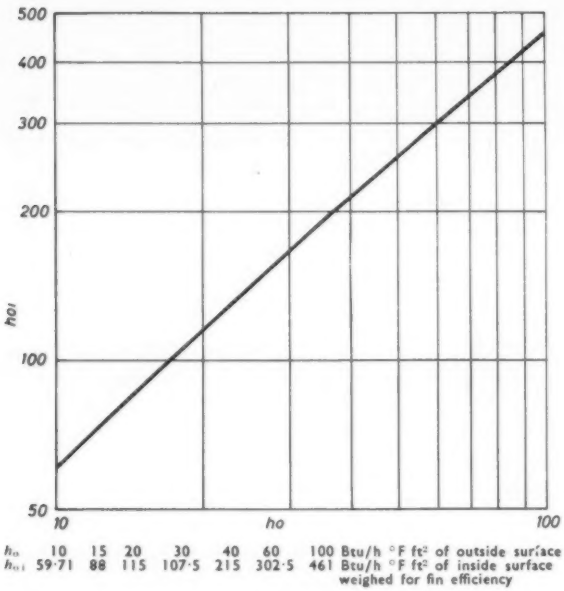
$$A_f = \frac{\pi(2{\cdot}786-2{\cdot}109)\,(2{\cdot}786+2{\cdot}109)}{24\times0{\cdot}1875} = 2{\cdot}31\ \text{ft}^2/\text{ft}$$

$$\text{Projected perimeter} = 2\left[1+\frac{(2{\cdot}786-2{\cdot}109)}{0{\cdot}1875}\right] = 9{\cdot}24\ \text{ft/ft}$$

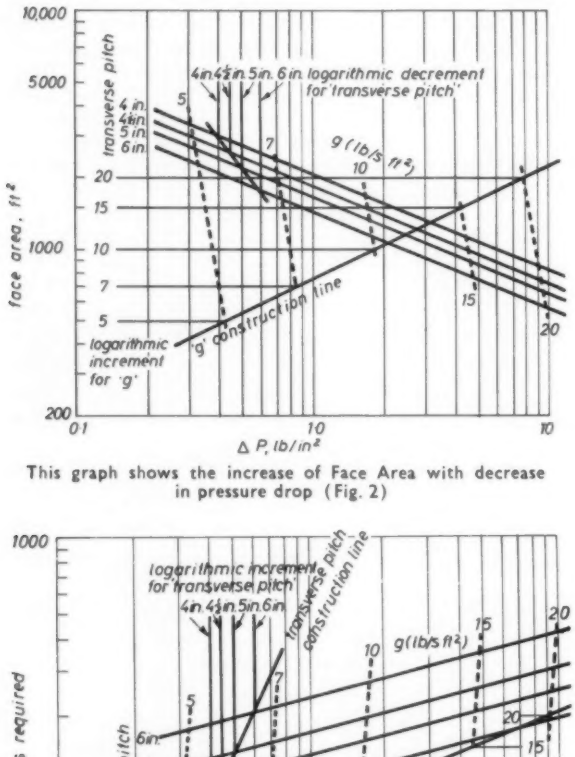
$$D_e = \frac{2(2{\cdot}31+0{\cdot}37)}{\pi\times9{\cdot}24} = 0{\cdot}185\ \text{ft}$$

$$\text{Projected area} = \frac{2{\cdot}109\times1}{12}+\frac{(2{\cdot}786-2{\cdot}109)0{\cdot}062\times64}{144} = 0{\cdot}195\ \text{ft}^2/\text{ft}$$

For any constant value of *Re*, the Free Flow Area, determined from a known total reactor coolant flow and tube geometry, must also be constant. For each transverse pitch selected there is a ratio (Face Area/Free Flow Area) which is easily determined. In this way, then, the




Conversion curve of the outside film coefficient to the inside (Fig. 1)




This graph shows the increase of Face Area with decrease in pressure drop (Fig. 2)




The number of rows decreases with the decrease in pressure drop (Fig. 3)

known and constant value of the Free Flow Area corresponds to a Face Area. This Face Area alters from pitch to pitch. Associated with this Face Area there is a given heat transfer surface which decreases as the transverse pitch increases. The surface required is, however, constant for any one value of *Re*, irrespective of pitch.

Again, it is reasonable to expect the pressure drop to vary as the number of rows in a bank of tubes and also as $Re^{-m}$ where '$m$' is the appropriate fraction index. Thus, for any constant value of *Re* there is a unique number of rows with its attendant pressure drop for one transverse pitch.

To begin the design it is necessary to select a specific tube. Expecting the value of $D_e$ to fall within the range 0·14–0·22 ft, a tube, the geometry of which gives a value of $D_e$ to be 0·185 ft is selected (Table 1). From this geometry a $(h_o/h_{oi})$ conversion curve can be constructed (Fig. 1).

If the Reynold's number, *Re*, be expressed as $(G\ D_e/\mu)$ where $G$ is the gas mass velocity based on minimum net Free Flow Area, then, for any range of values postulated

**TABLE 2** *Boiler units calculated for a value of* $g = 5$ *(lb/s ft²)*

| Section | LTE | LPB | HTE | HPB | HPSH | LPSH |
|---|---|---|---|---|---|---|
| $1/h_{oi}$ | 0·00819 | 0·00714 | 0·00685 | 0·00645 | 0·00614 | 0·00601 |
| metal resistance | 0·0007 | 0·0007 | 0·0007 | 0·0007 | 0·0007 | 0·0007 |
| $1/h_i$ | 0·001666 | 0·0005 | 0·001666 | 0·0005 | 0·01 | 0·01 |
| $1/U$ | 0·010556 | 0·00834 | 0·009216 | 0·00765 | 0·01684 | 0·01671 |
| LMTD | 68·8 | 58·2 | 57·6 | 73·8 | 56·13 | 120 |
| heat load $\times 10^{-6}$ | 437 | 584 | 190·8 | 945 | 194·2 | 122·2 |
| surface reqd. (ft²) | 67,000 | 83,600 | 30,550 | 98,000 | 58,300 | 17,050 |

| *Pitch*, in. | Rows required | | | | | | *Total* |
|---|---|---|---|---|---|---|---|
| 4 | 15·3 | 19·12 | 6·97 | 22·42 | 13·3 | 2·89 | 80 |
| 4½ | 19·5 | 24·5 | 9 | 29 | 17 | 5 | 104 |
| 5 | 24·4 | 30·4 | 11 | 35·2 | 21 | 6 | 128 |
| 6 | 34 | 42 | 15 | 49 | 29 | 8 | 177 |
| | Pressure drop, lb/in² | | | | | | |
| 4 | 0·05674 | 0·0719 | 0·0263 | 0·0854 | 0·051 | 0·0119 | 0·31 |
| 4½ | 0·058 | 0·0732 | 0·027 | 0·0872 | 0·052 | 0·0153 | 0·313 |
| 5 | 0·059 | 0·0750 | 0·0275 | 0·0893 | 0·054 | 0·0157 | 0·321 |
| 6 | 0·061 | 0·0769 | 0·0281 | 0·0916 | 0·055 | 0·016 | 0·328 |

for $G$ it is an easy matter to obtain the Free Flow Area, for any selected transverse pitch, since the total coolant flow is known. Boiler units can be calculated for each value of $G$, and the resulting values of pressure drop, number of rows of tubes, and Face Area may be plotted. A specimen calculation is shown in Table 2. The values 600 and 100 gives conservative results which may be amended at a later stage in the procedure. The value 2000 is conventionally adopted as the boiling coefficient.

From Fig. 2 it will be seen that, if the line connecting all the points '$g$' = 5(lb/s ft²) be projected downwards, it intersects the line corresponding to a Face Area of 500 ft², and if this be done for all lines of different values of $g$ it will be found that they intersect lines of Face Area of 500, 700, 1000, 1500, and 2000 for values of $g$ of 5, 7, 10, 15, and 20 respectively and that if all these interstices be joined they fall on the straight line called the '$g$ construction line'. Clearly, then, if a value of $g$ of 9 be required, then advantage may be taken of the fact that values of $g$ increase logarithmically along this '$g$ construction line', and at a value of the Face Area of 900 which intersects the construction line, a line parallel

**TABLE 3** *Calculation of Face Area for a range of values of 'g'*

4 IN. TRANSVERSE PITCH

For every ft² of face area there are 12/4 = 3 ft of tubing.
Projected area of this length of tubing = 3 × 0·195 = 0·585 ft².
∴ flow area per ft² of face area = 1 − 0·585 = 0·415 ft²
Inside surface per ft² of flow area = (1·66/12)11 × 3(1/0·415) = 3·14 ft².

| $g$ lb/s ft² | FLOW, ft² | FACE AREA, ft² | SURFACE PER ROW, FT² OF INSIDE SURFACE |
|---|---|---|---|
| 5 | $\frac{6972}{5}=1394{\cdot}4$ | $\frac{1394{\cdot}4}{0{\cdot}415}=3360$ | $1394{\cdot}4\times3{\cdot}14=4380$ |
| 7 | $\frac{6972}{7}=996$ | $\frac{996}{0{\cdot}415}=2400$ | $996\times3{\cdot}14=3125$ |
| 10 | $\frac{6972}{10}=697{\cdot}2$ | $\frac{697{\cdot}2}{0{\cdot}415}=1680$ | $697{\cdot}2\times3{\cdot}14=2186$ |
| 15 | $\frac{6972}{15}=465$ | $\frac{465}{0{\cdot}415}=1120$ | $465\times3{\cdot}14=1460$ |
| 20 | $\frac{6972}{20}=348{\cdot}6$ | $\frac{348{\cdot}6}{0{\cdot}415}=840$ | $348{\cdot}6\times3{\cdot}14=1095$ |

to all the other lines of different $g$ values, which are parallel, may be constructed, and the various values of Face Areas may be read off for whatever pitch is required.

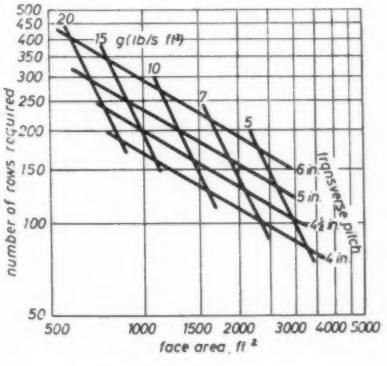
If the lines of constant transverse pitch are examined it will be seen that a similar condition exists, in that there is a similar construction line for transverse pitch along which values of the transverse pitch increase logarithmically. Knowing that these construction lines exist would have considerably simplified the derivation of Fig. 2. Instead of having to compute the Face Area and pressure drop for a range of values of $g$ and for each transverse pitch (Table 3), 4 points only need to have been calculated. For two values of $g$, two values only of the transverse pitch need have been considered, and the remaining lines constructed from the appropriate construction line.

Consideration of Fig. 3 shows a similar situation, instead of calculating each separate point (in Fig. 3 twenty different points were separately computed), four points only need have been calculated.

With this method it will be obvious that for any value of pressure drop, the size of boiler may be selected from the curves at will, and that any transverse pitch may be selected.

Inspection of Fig. 3 shows that with decrease of pressure drop the number of rows decreases, and that decrease in transverse pitch reduces the number of rows; but Fig. 2 shows that with decrease of pressure drop the Face Area increases, and with decrease in transverse pitch the Face Area also increases. This result is unfortunate since the pressure drop is required to be as low as possible. From Fig. 4, however, it will be seen that for any given Face Area it is beneficial to use the smallest transverse pitch. Similarly, Fig. 5 shows that, for any constant value of $g$, the length of tubing used is insenstive to transverse pitch but that the number of rows required is less with reduction in transverse pitch. It shows, too, that the greater the value of $g$, the less tubing is required.

This graph shows that for any Face Area the smallest transverse pitch is the most beneficial (Fig. 4)




From these design curves it is seen that for minimum pressure drop, the Face Area has to be large and the boiler height small. Since this large Face Area has to be accommodated in a cylindrical shell, clearly, the choice lies between many units of small diameter to give the same Face Area as a smaller number of units of large diameter. Unfortunately the choice of the number of boilers required is not in the hands of the boiler designer, exclusively, overall station considerations such as the method of blower drive and reliability in service, simplicity of layout, ductwork layout with its attendant expansions problem, and the overall station economy have determined that six boilers and six blowers per reactor is the desired number, using a variable frequency induction motor as the blower drive. Therefore, the largest Face Area which can be accommodated in six shells per reactor determines the boiler gas-side pressure drop. The problem, then, becomes: what is the largest shell diameter that can be manufactured. Expecting the diameter to be within the range 20–22 ft the Face Area would be 1560 ft².

For a constant value of 'g' the length of tubing required is independent of transverse pitch, but the number of rows required is less the smaller the transverse pitch (Fig. 5)

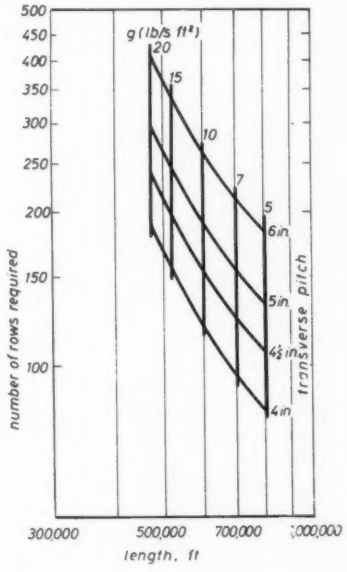



Figure 4 shows that it is advantageous to use a 4-in. transverse pitch and this pitch gives 134 as the number of rows required. From Fig. 5, using the same number of rows and transverse pitch, the length of tubing to be used is shown to be 605,000 ft, and Fig. 2 shows that the pressure drop is 2 lb/in². This does not include a margin.

If the margin be defined as (Installed Surface − Required Surface)/Installed Surface, and a margin of 15% be selected, then the overall pressure drop has to be increased to a value of $2/(1-0{\cdot}15) = 2{\cdot}355$ lb/in² and the number of rows increased to achieve this pressure drop, the Face Area remaining unaltered.

$$N = 135\times2{\cdot}355/2 = 157{\cdot}5 \text{ rows deep}$$

The boiler height corresponding to this number of rows is determined by the vertical pitch which, in turn, is determined by the criteria mentioned in ref. (*1*), namely that the velocity in the transverse pitch would be equal to that in the diagonal pitch. The vertical pitch which gives this condition is 2·45 in. which for convenience is increased to 2½ in., therefore,

$$\text{boiler height} = 157{\cdot}5 \times 2{\cdot}5/12 = 32{\cdot}8 \text{ ft}$$

The problem now is to determine the number of rows in each of the various sections of the boiler. Here use can be made of the fact that each point on Fig. 3 was individually calculated. At a 4-in. pitch and $\triangle P = 2$ lb/in² the value of $g$ is 10·6 lb/ft², so that values calculated for $g = 10$ may be used, modified as shown in Table 4. The number of rows necessary must be multiples of 2 or 4, dependent on the water path selected.

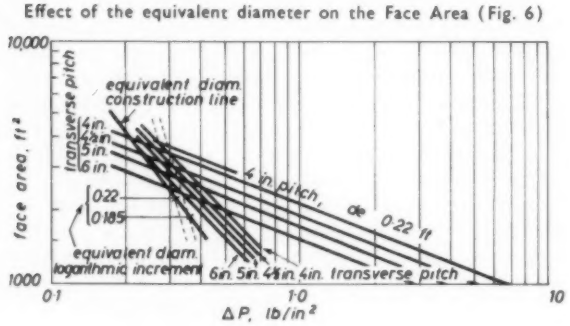
This design may now be accurately verified. The gas-side coefficients will remain unaltered but the inside coefficients will be changed considerably from the first approximation. These coefficients may be recalculated since the number of water paths is now known. Because of the increase of the inside coefficients, and by virtue of making the number of rows the next highest number which is a multiple of 2, the actual margins will have increased.

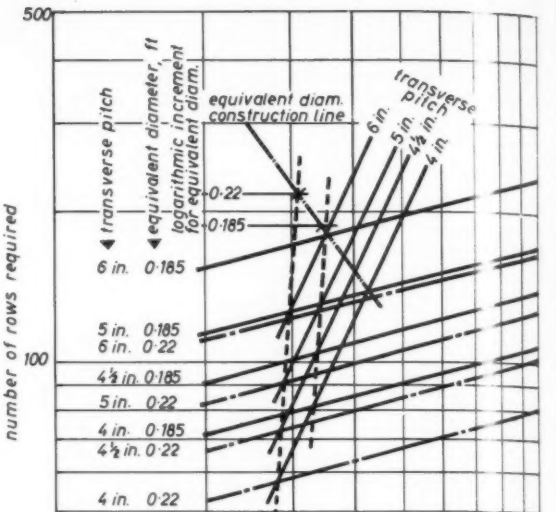
**TABLE 4** *Calculation of number of rows required*

| SECTION | NO. OF ROWS FOR $g = 10$ | NO. OF ROWS NECESSARY TO GIVE $\triangle P = 2{\cdot}355$ lb | ROWS TO BE INSTALLED |
|---|---|---|---|
| LPSH | 6·79 | $\frac{157{\cdot}5}{118{\cdot}92} \times 6{\cdot}79 = 8{\cdot}99$ | 10 |
| HPSH | 23·15 | $\frac{157{\cdot}5}{118{\cdot}92} \times 23{\cdot}15 = 30{\cdot}66$ | 32 |
| HPB | 30·75 | $\frac{157{\cdot}5}{118{\cdot}92} \times 30{\cdot}75 = 40{\cdot}73$ | 42 |
| HTE | 10·18 | $\frac{157{\cdot}5}{118{\cdot}92} \times 10{\cdot}18 = 13{\cdot}48$ | 14 |
| LPB | 26·2 | $\frac{157{\cdot}5}{118{\cdot}92} \times 26{\cdot}2 = 34{\cdot}7$ | 36 |
| LTE | 21·85 | $157{\cdot}5 \times 21{\cdot}85 = 28{\cdot}94$ | 30 |
| Total: | 118·92 | 118·92 154·5 | 164 |

All the foregoing is for a tube whose geometry gives an equivalent diameter of 0·185. If Fig. 6 is examined, the effect of the equivalent diameter on Face Area is shown. The lines transversing the figures are essentially those from Fig. 2 for various transverse pitches. From the curve it will be seen that, as the equivalent diameter increases, so too does the Face Area to give the same pressure drop. The 'equivalent diameter construction line' has been constructed similarly to the construction lines previously described. On the curve are lines of constant pitch so that if one pitch is selected, an equivalent diameter may easily be found. It should be noted that, as the equivalent diameter increases, there is a minimum transverse pitch to give equal velocities in both the diagonal and transverse pitches. Figure 7 shows the effect of equivalent diameter on the number of rows required, as the equivalent diameter increase the number of rows decreases.

Effect of the equivalent diameter on the Face Area (Fig. 6)




How the equivalent diameter affects the number of rows required (Fig. 7)

With the value of the face area known, it is obvious from Fig. 6 that for minimum pressure drop the equivalent diameter has to be as small as possible, but from Fig. 7 the equivalent diameter has to be as large as possible, to give the smallest number of rows. If curves similar to Figs. 4 and 5 are constructed it will be seen that the equivalent diameter and the transverse pitch both need to be as small as possible.

From Fig. 6 it could perhap be argued that the smallest Face Area is associated with small transverse pitch and large equivalent diameter. But as has previously been pointed out, to limit the velocity in the diagonal pitch to that in the transverse pitch, 4-in. transverse pitch with a $D_e$ of 0·185 ft is the practical limit. If a larger value of $D_e$ were selected with a smaller pitch, the fins on the tubes would foul in the diagonal pitch.

The finished design resolves into 6 boilers per reactor, each 21 ft dia., using transverse fins as indicated in Table 1, deployed on 4-in. transverse pitch and 2½-in. vertical pitch in staggered formation. The height over the tube banks corresponds to 164 rows, and is 34·2 ft high. There are five interbank spaces each at 2 ft 6 in. and allowing for hemispherical ends the total boiler height becomes 67 ft 8 in. The pressure drop over the tube banks is 2·4 lb/in².

**References**


1. Ediss, B.G., Bilsborough, R., and Carr, F., NUCLEAR POWER, 1959, **4**, July 80–82; August, 95–98.
2. Jameson, S. L., *Trans. ASME*, 1945, **67**, 633–642. See also Gardener, K. A., *op. cit.* 621–632.
3. Gunter, A. Y., and Shaw, W. A., *op. cit.*, 643–660.

Berkeley will be one of the first nuclear power stations in the UK to change fuel while the reactors are on load

# Fuel handling at Berkeley

In commercial nuclear power stations, loading and unloading operations should be carried out while the reactor is on power to assure continuous generation of electricity; the control equipment must be able to be withdrawn for servicing; and an accurate assessment needs to be made of the future requirements of the reactor. As well as being completely heat-resistant and pressure-tight, the charge face machinery must also be able to withstand gamma rays and be immune from neutron activity so as to provide adequate protection for the charge face operators.

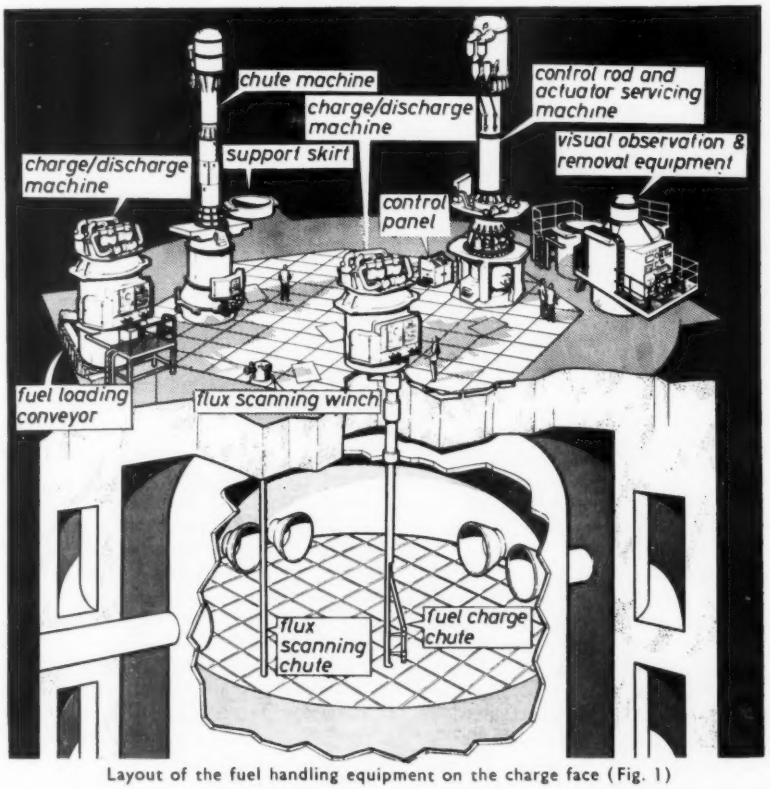
John Thompson Ordnance Co., Wolverhampton, the precision engineers of the John Thompson Group, have been engaged for the past three years in the design and production of the fuel handling machinery for Berkeley. The production of the equipment called for the use of specially selected machine tools and rigidly controlled conditions, including high standards of cleanliness and constant atmospheric temperatures. Some idea of the accuracy with which the charge face machinery is made is shown by the fact that charge chutes when selecting one fuel channel from a possible 3000 must do so from a distance of 40 ft and to within 0·22 in.

The choice of materials for making the machinery, and the production methods used created numerous problems surmounted only by extensive research. All materials must be compatible and difficulties were encountered with such items as rotating bearings, etc. When welding the assemblies, differences in clearances between stainless steel and mild steel had to be taken into account.

At Berkeley, the general conception of fuel handling had been to use separate functional machines so that there are five machines rather than one or two multi-purpose machines. These comprise charge/discharge machines, chute machine, and control rod and actuator servicing machine (Fig. 1).

Three of the large machines are designed for refuelling the reactor while under load. Access to the 3000 reactor fuel channels, each of which contains 13 elements, is by means of 60 charge standpipes led through the biological shield. Each standpipe is surmounted by a flap valve.

The chute machine is first brought into use. The required standpipe is prepared and an operational shield skirt lifted into place and lined up.

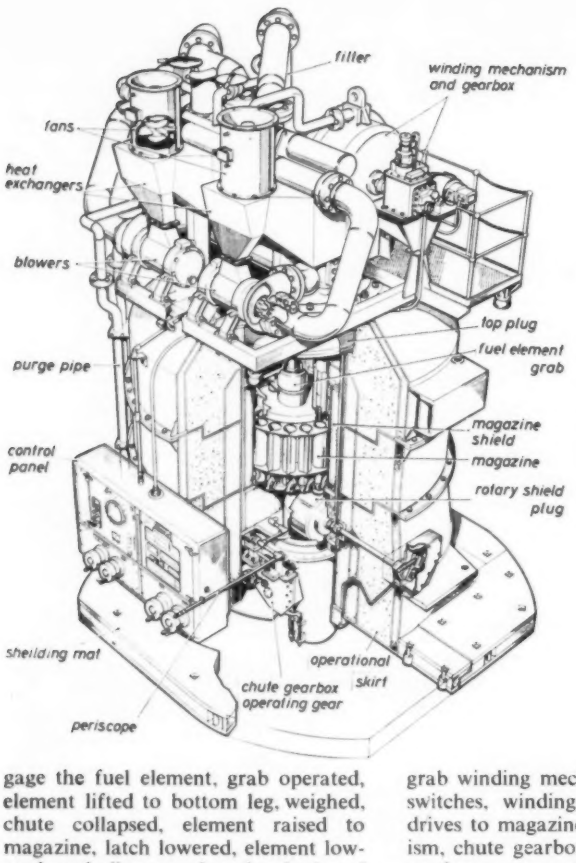



Layout of the fuel handling equipment on the charge face (Fig. 1)

The chute machine is then lifted onto this, using the overhead crane which has a forked mast. The seal is made and the machine pressurized. The flap valve is opened by remote control and the grab lowered to engage the shield plug in the standpipe. This is lifted out, and secured in one chamber of the 3-part magazine of the machine, which is some 55 ft high. The grab is released and the magazine rotated, the grab then engages the chute which is lowered into the standpipe, and enters a socket above the graphite core. The chute can be rotated and its lower leg extended. After release and withdrawal of the grab the flap valve is shut and the machine purged of gas and removed.

The discharge machine is next brought up and coupled to the standpipe. When pressurized and with the flap valve open, the lowest portion of the machine is lowered through the valve to engage the head of the chute and allow operation of it.

The discharge machine is fully automatic in operation. The zircaloy grab is lowered to the bottom leg of the chute, leg raised, grab lowered to en-




The charge/discharge machine, essentially a winding mechanism, rests on an operational skirt. The fans of the circulating cleansing and cooling system, normally using air but substituting $CO_2$ when connected to the reactor, are powered from trailing cables (Fig. 2)

gage the fuel element, grab operated, element lifted to bottom leg, weighed, chute collapsed, element raised to magazine, latch lowered, element lowered, grab disengaged, grab raised, and finally the magazine indexed.

The machine does this for all thirteen elements and also removes and replaces the shield plugs in the chute head, in the course of about 75 minutes. It then indicates completion.

Sealed off and purged, the machine, which incorporates heat-exchange cooling, is transferred to the discharge point, and the sequence of operations is altered by a punched card substitution. It then automatically discharges its load to the flask at the bottom of a long discharge shaft.

Meanwhile the charge machine, which is identical in construction with the discharge machine, has been charged with new fuel over the loading point. Transferred to the standpipe and pressurized, it charges the fuel channel from its magazine. This is done under automatic control as for discharge. For special operations such as gag changing, selection controls can be used such as sequence button operation and hand control, each handle having a slipping clutch incorporated to limit the torque. The requirement is to change 10 channels per week after 2 years.

## Charge and discharge machines

The main constituents of each of these machines are fuel element grab, grab winding mechanism, and control switches, winding gearbox assembly, drives to magazine and latch mechanism, chute gearbox and standpipe operating gear, control panel and its mechanism, and circulating and cooling equipment (Fig. 2).

Basically the charge/discharge machine is a winding mechanism controlling a grab which can engage or disengage from a fuel element, etc., as required. A rotatable magazine can accommodate 13 fuel elements and also a reflector, a gag and a spare, and four concrete plugs are fitted to reduce the effect of radiation; in the bottom plug is a rotary shield to seal-off the channel used by the grab. All the machinery is contained in a pressure vessel, shielded on the outer side to give the necessary protection, and built to withstand the working pressure in the reactor.

For operating the machinery, drives (power and hand), electric indicator wiring, etc., pass through the pressure vessel and shielding to a control panel in which routine operations can be automatically controlled by means of relays, uniselector switches and a selective card system. A fully comprehensive system of interlocks (both mechanical and electrical) prevent actions which may cause damage or prove dangerous.

To operate, a machine must rest on a skirt; the loading conveyor skirt, the discharge well skirt, or an operating skirt. When not operating, the machine rests on a parking skirt. The machine, weighing approximately 100 tons, must be lifted by crane from one skirt to another.

Three machines are fitted with each reactor; the charge and discharge units on the charge face for operational purposes, and a standby machine, ready for service, but not fitted with shielding.

## Chute machines

The machine includes a charge chute for use with the charge/discharge machine; flux scanning chute used in conjunction with the flux scanning winch; fixed absorber chute used with the control rod and actuator servicing machine crasm; thermocouple chute to work with its own winch vessel; reactor periscope; standpipe plug which normally closes and shields the bore through the charge standpipe; metal samples handling chute; graphite sample trailing thermocouple chute; and charge standpipe sealing plug.

Two machines are supplied for each reactor charge face, the spare replacement unit not being fitted with shielding. Because the chute machine operates with the reactor on load, it includes a pressure vessel which can be connected to the reactor, via the standpipe (Fig. 3).

The chute machine's equipment comprises a grab and winding mechanism to raise or lower the chute; a rotating three-chambered magazine to store two chutes; mechanism to cause the grab to connect with or release its load, and to support a released load in the magazine.

Outside the main shielding on which the pressure vessel is supported, is a control panel for operating the machine.

The chute machine is placed by the crane on a operational skirt when working over a charge point, over the inspection well, the discharge well, or the decontamination well. With the exceptions of the high parking skirt and the loading skirt, the machine can be placed on any support skirt. Electrical interlocks prevent lifting until machine and standpipe have been correctly prepared. Interlocks, all of which operate 'fail to safe' also prevent incorrect operation of the machine.

## Control rod servicing machine

The reactor contains a large number of control rods which can be lowered or raised from the graphite core as part of the reactor control system. Most of the control rods are connected by wire cables to electrical winches. These winches, called actuators, are about 15 in. dia. 12 ft long

(including shielding plug), and weigh 15 cwt. The actuators are in the pressure system and are secured in the biological shield in specially shaped standpipes. Screwed rings which secure the actuators are turned by a motor and gear ring, known as the actuator clamping machine, which must be attached to the actuator during its removal or replacement in the standpipe.

The machine is used to exchange actuators and control rods, gags, fixed absorbers, etc. The complete unit comprises a magazine section containing grabs and their winding gear, and a support, or skirt section complete with various tools by means of which the actuator can be separated from or connected to its control rod. The skirt section is also used with the visual observation and recovery equipment when necessary. Both sections can withstand, either separately or together, the gas pressure in the reactor, and can be operated while the reactor is on load. (For brevity, the machine is called crasm, Fig. 4.)

**Magazine and skirt sections**

About 40 ft high and 5 ft in diameter, the magazine section together with its shielding, weighs 85 tons. Shielding is fitted in a structure which allows the main crane to lift the complete unit.

A 90-in. dia. ball bearing on which the pressure vessel and the major portion of the shielding can be rotated in the vertical plane, is situated in the shielding structure.

Four magazines are contained in the pressure vessel: one for a clean (uncontaminated) actuator; one for a dirty (radioactive) actuator; one for a clean control rod; and one for a dirty control rod. Each magazine contains its appropriate grab which is raised or lowered by an independent set of winding gear. The operating gear for winding gears, for grab operation, for rotating shields in the bottom of the magazine, and for four flap valves which seal the vessel, pass through the vessel and shielding where appropriate. Operating gear is driven by electric motor and gearboxes on the outer surface.

Dimensions of the skirt section and its shielding are, roughly, 10½ ft dia. and 8 ft high, and its weight is 65 tons. The pressure vessel has two operating tools; a manipulating tool and a cable recovery tool. The former provides the means whereby the control rod is disconnected from or connected to the cable on the actuator, and the latter supplies a means of recovering the control rod and its cable, should an actuator become defective. To assist in these operations, two periscopes are fitted. A rotary shield and two flap valves seal against radiation and pressure, and a separate sleeve is provided to bridge the gap between the standpipe and the bottom of the skirt.

As a separate unit, the control panel is on a trolley connected by electric cables to the power supply and to both the magazine and skirt sections. When the visual operation and recovery equipment is in use with the skirt section, the control panel links the skirt and control panel on the recovery equipment.

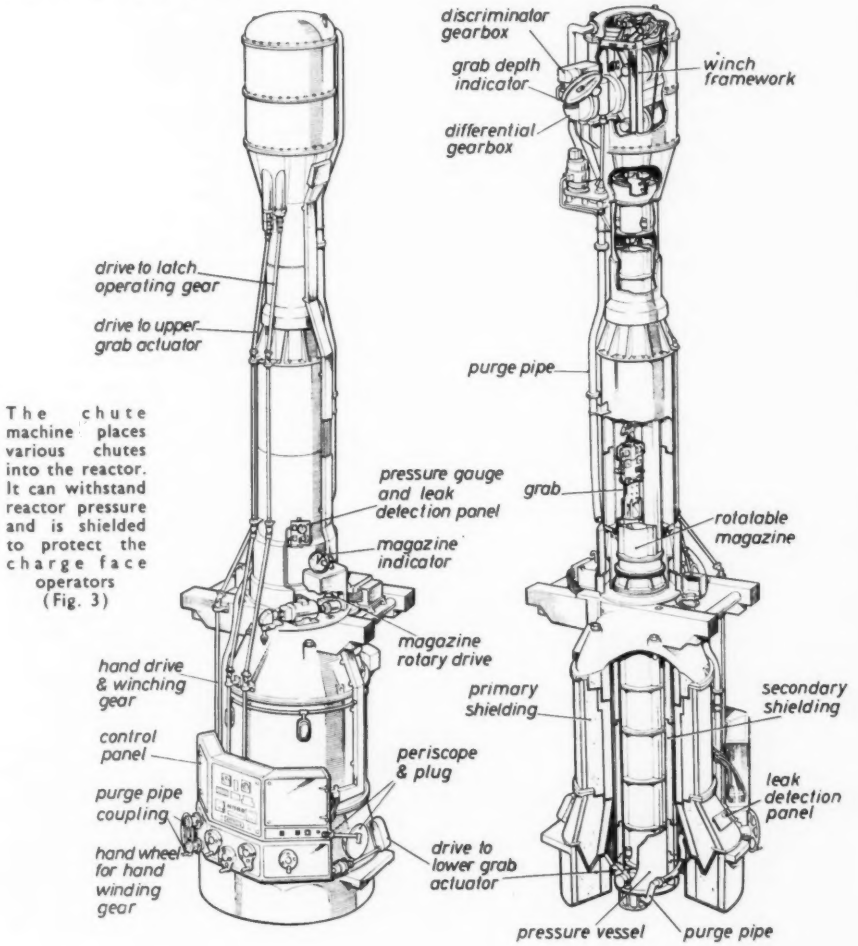
The skirt, placed by the crane over either an actuator standpipe or a charge standpipe, rests flat on the charge floor plates and the connexion to the standpipe is made by the appropriate sleeve. When operations on the reactor are to be carried out the magazine can be placed on a skirt. It is placed on an operational skirt over the inspection well or the chute decontamination hole, for reloading or discharging. It can be positioned on any of the skirts on the charge face floor and electric interlocks prevent either magazine or skirt being lifted unless properly prepared.

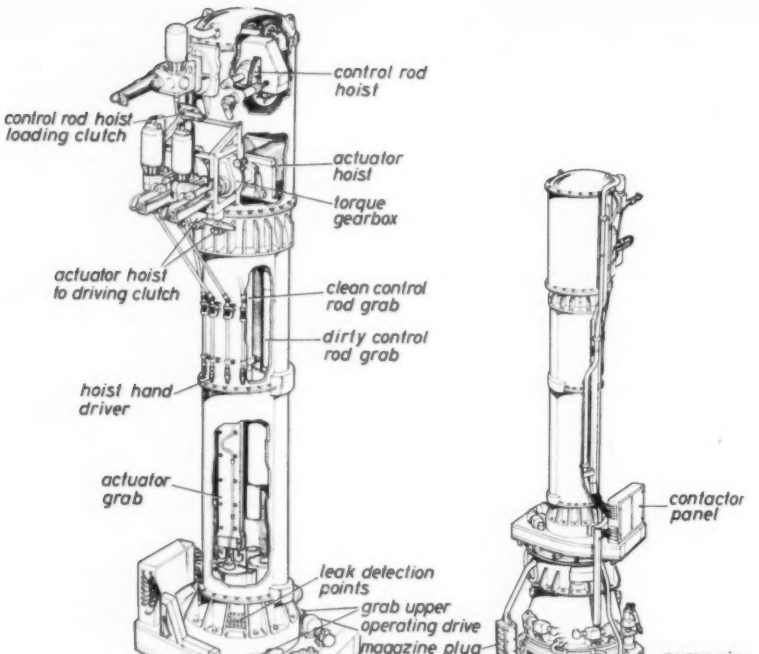
**Support skirts**

With the exception of the crasm skirt, which itself is a pressure vessel and a machine, all skirts are, basically, support structures. Semi-permanent support skirts for the loading conveyer; for the discharge well; and for both low and high parking, are provided for each reactor, which also has three moveable operational skirts. The design of support skirts varies only in shielding requirements and overall height.

*Loading conveyer skirt* This is semi-permanently positioned over the loading conveyer to locate and support the charge machine when it is being re-filled. It is 5 ft 3 in. high and contains 15¼ in. of iron shot concrete in its walls. A separate platform on the outside gives access to the machine's controls.

*Discharge well skirt* Semi-permanently positioned over the discharge well and the adjacent chute decontamination hole, this skirt locates and supports the discharge machine, the chute machine, the visual observation and recovery equipment (vore), the chute mechanism, and the crasm


discriminator gearbox
grab depth indicator
winch framework
differential gearbox
drive to latch operating gear
drive to upper grab actuator
purge pipe
The chute machine places various chutes into the reactor. It can withstand reactor pressure and is shielded to protect the charge face operators (Fig. 3)
pressure gauge and leak detection panel
grab
rotatable magazine
magazine indicator
magazine rotary drive
hand drive & winching gear
primary shielding
secondary shielding
control panel
periscope & plug
purge pipe coupling
leak detection panel
hand wheel for hand winding gear
drive to lower grab actuator
pressure vessel
purge pipe




The control rod and actuator servicing machine exchanges actuators, control rods, gags and fixed absorbers (Fig. 4)

magazine for discharging. The skirt is 2 ft 6 in. high and contains 4 in. of lead and 19¼ in. of iron shot concrete in its walls.

*Low parking skirt* This unit is semi-permanently positioned near the entrance to the maintenance bay. It is 2 ft 6 in. high, but its walls have no shielding.

*High parking skirt* Semi[-]permanently positioned near to the l[-] parking skirt, this unit can ac[-]t any machine. It is 7 ft 1¼ in. hig[-] and its walls contain 8 in. of lead an[-] 11⅞ in. of iron shot concrete. Insid[-] it are guides, provided to enable t[-] crane to position the skirt as requir[-]d.

*Operational skirt* This is p[-]itioned where required on the cha[-]e face floor and can accept any [-]achine. From inside out, the walls c[-]sist of 16¼ in. of borated polythene on the inside and 3 in. of lead on the outside and the unit is 2 ft 6 in. high. Header tanks, connected permanently to the polythene-filled ring, allow for the expansion or contraction of the polythene mixture under extremes of temperature. Air release plugs are screwed to the top of the skirt for manufacturing purposes and pads, at the base, allow the attachment of dowel brackets for location over the inspection well, etc. Friction pads are fitted on the bottom surface to prevent movement while the skirt is resting on the floor and extra shielding, made of borated hydroboard enclosed in fabricated plating, extends outside the bottom of the ring.

## Fuel element loader and conveyer

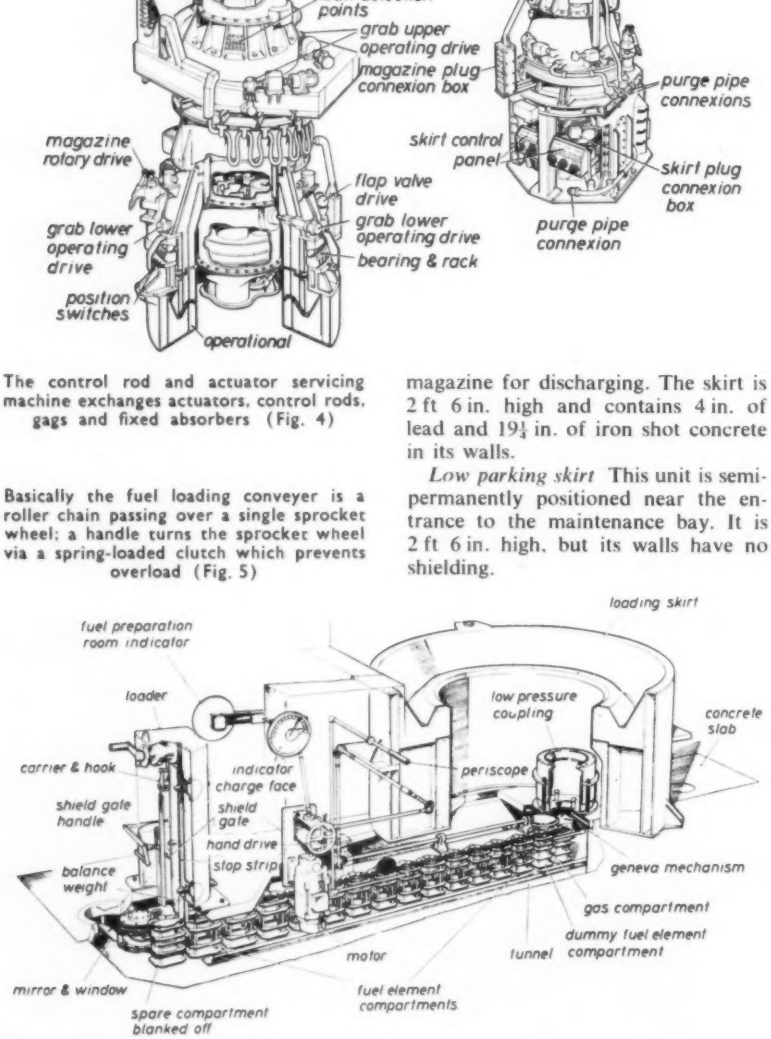
This equipment is used for loading fuel elements into the charge machine and comprises loading skirt, low pressure coupling, loading conveyer and its loader (Fig. 5).

The conveyer consists of two horizontal endless chains passing around four sprocket wheels, each pair on a vertical axle. Supported between the chains are 16 compartments of approximately the same section as the tube used in the charge machine magazine. Stops fitted in the bottom of the compartment hold the fuel element which is lowered into them by the loader, and raised from them by the fuel element grab in the charge machine. The spacing of the compartments is such that they extend over half of the conveyer only: when the first is under the skirt, the other is under the loader. Five spacers are fitted in the blank portion of the conveyer to maintain the correct spacing between the two chains.

A motor and gearbox, mounted on the charge face wall drives the conveyer.

Loader casing is made up of one plain tube for the balance weight and another tube of the same sections as those in the charge machine magazine; the latter tube is cut away to allow a fuel element to be inserted. Two flat plates fill in the sides of the casing which is surrounded by iron shot concrete shielding in a steel retaining shell.

Basically the fuel loading conveyer is a roller chain passing over a single sprocket wheel; a handle turns the sprocket wheel via a spring-loaded clutch which prevents overload (Fig. 5)



# STUDENTS' NOTEBOOK

## GROUNDWORK—Information

*What are the basic methods for obtaining information on atomic energy?*

The volume of published information on scientific and technical subjects is rapidly growing each year and it becomes increasingly difficult for the research and technical worker at any level to keep abreast with current developments. A bewildering number of reports, conference papers, symposia, original articles in journals, books, patents and trade literature form the material for study.

Some large organizations possess good information services that are well equipped to ease the burden of search but many of our readers are either not so fortunately placed, or they may prefer to find information for themselves. The key to published information is the bibliography and the abstract service, which in the nuclear field is fairly adequately covered.

'Nuclear Science Abstracts', NSA, was initially issued by the USAEC for use by government research establishments and contractors, but it now has a world-wide distribution. In addition to giving indicative abstracts of all declassified reports from the AEC, it covers reports from non-contractual organizations in the USA, other atomic energy authorities, translations, journal articles, books and patents. Publication started in 1947 since when it has steadily increased its coverage. Each issue, which is fortnightly, now contains indexes to subjects, authors, organizations and reports, and these appear in cumulative form quarterly, half-yearly and annually.

In common with most published abstracts, NSA is some months behind but many of the AEC reports do appear, in listed form only, far sooner in the official 'US Government Research Report'. Using these publications, it is easy enough to compile a reading list on any nuclear subject but the next problem is where to obtain the material. Fortunately, there have been established in this country a number of depository collections for USAEC and UKAEA reports administered by selected public library authorities; these are at London (Acton), Birmingham, Bristol, Kingston-upon-Hull, Leeds, Liverpool, Manchester, Newcastle, Nottingham and Sheffield. It is a condition that all deposited material should be made available for loan to industry and others, preferably through librarians where they exist, but there is no reason why requests from individuals should not be met.

As far as the UKAEA is concerned, a very useful publication to consult is the monthly 'List of publications available to the Public' which consists of original documents and translations, together with articles in periodicals contributed by the Authority staff. Apart from a number of very useful bibliographies compiled by the Harwell and Risley libraries, there is also available a complete guide to 'Sources of Information in Atomic Energy' in the form of a Harwell publication AERE-Lib/L1 (3rd edition) 1960. All these are available for purchase through HMSO.

## VISUAL AIDS—Films

Practical experience with reactors is available only to a limited number of students; for others the film medium must provide the nearest approach to that experience. The modern technical film is a valuable asset in training courses, especially when actual scenes of reactor operation can be linked with theoretical diagrams. American technical films of reactor topics are most numerous and cover a wide variety of subjects, but British films of this type are, in general, excellent and increasing in number. European countries do not appear to have exploited the nuclear technical film to any large extent.

We give below a selection of films for the beginner and the more advanced student.

*A is for Atom* An entertaining colour film giving in cartoon form an elementary account of the principles of nuclear fission reactions. It is useful as an opening film in a nuclear reactor course. (15 minutes) (Central Film Library, London 16 mm Sound Colour £1 per day)

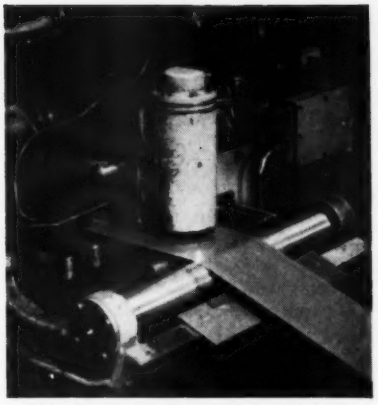
*Isotopes* This is an introduction to theory and application, designed for science specialists in grammar schools and technical colleges. (15 minutes) (Education Foundation for Visual Aids, London 16 mm Sound Colour)

*Radioisotopes in Industry* Shows the organization for the preparation and despatch of radioisotopes, particularly short-lived isotopes. Many applications are illustrated but these are somewhat crowded towards the end of the film. (About 30 minutes) (UKAEA, London 16 mm Sound Colour Free hire)

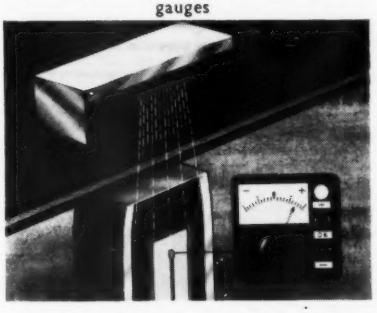
*Marcoule, Cité Atomique* Surveys French progress in the nuclear energy field, illustrating particularly the G1, G2 and G3 reactors. English Commentary. (About 40 minutes) Institut Français du Royaume Uni, London 16 mm Sound Colour 7/6 per day)

*Criticality* The dangers of accumulating an overcritical mass of fissionable material are strikingly shown in colour by animated diagrams and scenes of factory practice. Not a recent film, but one well worth seeing. (About 30 minutes) (UKAEA, Harwell 16 mm Sound Colour Free hire)

*Metals of the Nuclear Age* The metallurgy of uranium, plutonium and the newer metals for fuel canning. Uses diagrams most effectively. Some metallurgical background is an advantage for a full appreciation of this excellent film. (About 35 minutes) (UKAEA, London 16 mm Sound Colour Free hire)



Stills from the film 'Isotopes' show (above) thickness measurement applied to rolling metal strip and (below) the principle of thickness gauges



*Spert I—Experiments in Nuclear Reactor Safety (USA)* A most striking film illustrating power excursions in a swimming pool type of reactor. Shots of the sudden onset of boiling and the eruption of the water are linked to graphical diagrams of power changes. Flashes of Cerenkov radiation are very well shown. Definitely a film for the student with some understanding of reactor control problems. (About 35 minutes) (USAEC, London 16 mm Sound Colour Free hire)

## NEWSBRIEFS

- The Institution of Chemical Engineers have revised in part the regulations for admission to the classes of Graduate and Associate Membership. The revisions are mainly concerned with the definition of exemption from examination qualifications.
- A permit to build a Triga II reactor on the Illinois University campus is to be granted by the USAEC who are making a £53,000 grant and lending the fuel without charge.
- The FBI Overseas Scholarship Scheme, introduced in 1950, has resulted in the training of 357 engineers from 37 underdeveloped countries in over 300 British firms.

## UK COURSES

**Borough Polytechnic, London.** Reactor control and instrumentation. Commencing 7.00 on Thursday, 28th April, and subsequent Thursdays up to 26th May. Fee: 10s.

The second article in this series discusses the design and use of apparatus for the measurement of radiation exposure

# *Health physics instrumentation—2*

*by* DENIS TAYLOR, M.Sc., Ph.D., M.I.E.E., F.Inst.P.,
*Plessey Nucleonics Ltd.*

IT IS WELL KNOWN that in the early days of radiation dosimetry the roentgen was accepted internationally as the unit for expressing X-ray exposure. The unit was based on the concept of the free-air ionization chamber, which is still the basis of standardization measurements. It may be noted that the free-air ionization chamber is capable (*1*) of a precision of the order of 0·5% in measurement of X-rays generated by voltages between 50 and 500 kV. In the case of higher energies the free-air chamber becomes impracticably large and so it is necessary to use various secondary radiation meters which may be calibrated against the free-air chamber as a standard. Free-air chambers are, in fact, seldom used outside the national standards laboratories, and in industry wide use is made of these secondary instruments.

For normal use a smaller and more robust type of ionization chamber is required. Chambers of this type can be calibrated against a free-air chamber, and so it is not necessary that its response should be exactly calculable. On the other hand it is desirable that its response to different energies shall not be different from that of air (or tissue if the biological dose is required). This is achieved by making the walls and electrodes of the chamber of materials whose atomic number is not very different from that of air (or tissue if the tissue dose is required). Instruments for the measurement of X-ray and $\gamma$-radiation are often made of plastic. Although it is permissible in some cases to use wall-material which is not quite tissue-equivalent, it is necessary to avoid the use of materials of high atomic numbers, to avoid enhanced response at certain energies. In the case of $\gamma$-radiation it is reasonable to mix materials so that the average atomic number corresponds to that required to be air-equivalent or tissue-equivalent. However, in the case of chambers used for measuring neutron exposure more careful design is necessary, because detection in this case is through interactions with the nuclei present, and this necessarily means having the correct materials present.

## Instruments for radiation exposure

Instruments for the measurement of radiation exposure usually comprise a radiation detector and a suitable measuring circuit feeding a presentation unit. The latter may take the form of an aural or visual indicator, meter indication being the most common. Depending upon the circuit arrangement, a given instrument may indicate dose rate or integrated dose, but rate indication is invariably preferred in health physics surveys.

Ionization chamber detectors tend to be employed for these instruments, because of the simplicity of relating the measurements to a standard free-air chamber for calibration purposes. The currents produced by ionization chambers for the usual order of measurement required (i.e. around rates corresponding to the maximum permissible level for a working day, 7·5 mr/h) are of the order of a micromicroamp even if a large volume ionization chamber is employed. Hence it is necessary to associate with the ionization-chamber detector a very sensitive direct-current amplifier, and a thermionic valve with a specially high input resistance (low grid resistance) is essential. One-valve instruments are common for simple survey measurements, but greater flexibility is possible using two or more valves. The more elaborate circuits allow greater precision of measurement of dose rate, shorter response time, or improved linear response. So far transistors have not been produced capable of replacing the first (electrometer) stage of these units, but it is possible to design a suitable amplifier for use with an ionization-chamber detector comprising a first-stage electrometer valve, followed by a number of transistor stages, and this appears to be the design pattern to be followed for the next few years.

Survey meters of the portable type generally employ switched linear ranges. A typical instrument may employ, for example, three ranges covering 0–12·5 mr/h, 0–125 mr/h, and 0–1250 mr/h. In some cases measurement over a wide range of dose rates is required. It is then possible to follow the ionization-chamber detector with a logarithmic amplifier, and instruments of this type are very popular, particularly for dose-rate measurements at fixed locations. Such instruments are much used around reactor plants, particle accelerating machinery, etc., and are often arranged to feed an output to a chart recorder and to operate alarms when the dose-rate exceeds some pre-set figure. They are also employed to operate interlocks preventing entry to certain areas around reactor plant, etc., when the measured dose-rate at these locations exceeds the mpl.

Geiger counters are widely used for special purpose survey meters. Such instruments provide an indication which is proportional to the number of ionizing particles which enter its sensitive volume, rather than to the total ionization produced. It is possible, therefore, to calibrate geiger-counter instruments to read dose-rate where a single kind of radiation is present, but they cannot be used to determine dose-rates where mixed radiations are present. Geiger-counter instruments can, therefore, be employed as dose-rate monitors, but their limitations should be clearly

understood. Their chief application, because of their high sensitivity, is for rapid survey work in the detection and location of spills and contamination (2).

Geiger-counter detectors are employed with a ratemeter circuit and may be arranged, if required, to operate a chart recorder. It is possible to use transistor circuits and, therefore, very compact, light-weight instruments may be designed. One limitation which is worth noting is that geiger counters have a comparatively long dead time (3), after each pulse, which means that they cannot be used above a certain fixed counting rate. This can lead to difficulties as in high intensity fields they may be paralysed and give a dangerously low reading.

In the last few years scintillation-counter detectors employing a scintillator and a photomultiplier tube have been much used in health-physics instruments. For gamma-ray measurements a sodium iodide scintillator has been employed extensively to provide information about the energy spectrum of the radiation, as well as for dose-rate measurements. It has the advantage that it can operate in much higher intensity radiation fields than a geiger-counter. Thin organic crystals may be employed for the selective counting of beta-particles and plastic phosphors are now available which may be employed for counting fast neutrons.

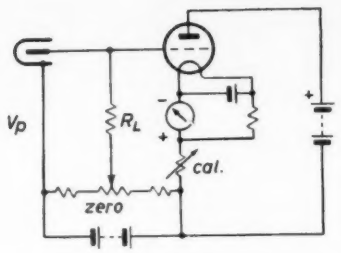
The new photoconductive crystals (4) seem likely to offer the possibility of a very inexpensive survey suitable for civil defence applications, but it is not clear whether they will compete with ionization-chamber instruments where reasonably high precision is required. They do not compete with scintillation-counter instruments where measurement of mixed radiations is required, but for health physics applications where, for example, a criticality incident is involved, they may be of great value because of the simplicity of their measurement system which, of course, adds to the reliability of the system.

## Ionization-chamber instruments

The simplest type of apparatus for the measurement of dose-rate uses an ionization chamber feeding into an electrometer valve circuit as shown in Fig. 1. It will be seen that the electrometer valve circuit is employed to measure the voltage developed across a load resistor by the output current from the chamber. The ionization current is given by $I = 9{\cdot}26 \times$ chamber volume in $cm^3 \times$ dose-rate in $r/h \times 10^{-14}$A.

The simple circuit as shown in Fig. 1 has various limitations. These are limitations in sensitivity and due to reverse grid-current ($I_g$) in the electrometer valve, leakage currents across grid-circuit insulation, and slow response times with high values of the load resistance. It will be noted that a zero setting is provided. When checking the zero setting it is desirable to short-circuit the load resistance to ensure that incident radiation is not contributing to the reading.

When considering the design of a dose-rate monitor it is necessary to realize that the product $I_g \times R_L$ must be small compared with the working grid swing $\triangle V_g$ of the electrometer valve. This means that if the grid current is of the order of $10^{-13}$A, it is reasonable to use this electrometer for the measurement of ionization currents down to $10^{-11}$A. With very low dose-rates the ionization current from small chambers may be less than this (i.e. less than $10^{-11}$A) as can be seen from the formula above. It is possible to increase the ionization current by using a pressurized




Electrometer valve circuit fed from an ionization chamber gives simple dose-rate measurement (Fig. 1)

chamber. This is a satisfactory solution if a gamma-radiation measurement only is involved. In some cases, however, survey instruments are required to measure beta- as well as gamma-radiation. This means providing the ionization chamber with a beta-sensitive window which has to be covered by a plate when making a gamma-dose measurement. Sometimes the double measurement is unacceptable, and it is then necessary to use the type of instrument illustrated in Fig. 2, which uses a double ionization chamber. One part of the chamber is sensitive to gamma-rays only, whereas the other part of the chamber is sensitive to (beta + gamma) radiation. The chambers are arranged in opposition so that the current from the collector electrode is a measure of the beta-dose.

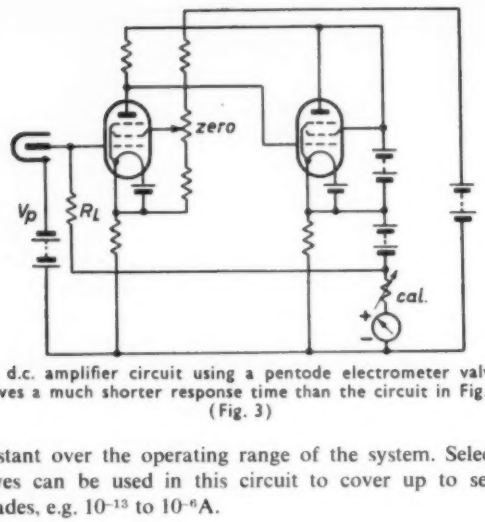
Consideration of the leakage current across the grid-circuit insulation is an important design factor to be considered. It is useful to employ a guard ring (5) in the chamber. This has the effect of minimizing the effect of leakage via the chamber insulation resistance ($R_c$) with the guard ring connected to a bias voltage between the collector and polarizing electrodes. The maximum leakage current is then $\triangle V_g/R_c$ instead of $V_p/R_c$ and only the collector-to-guard ring insulation is highly critical.

The time constant obtainable with the simple circuit shown in Fig. 1 is of the order of a few seconds. To achieve shorter response time it is necessary to employ a more elaborate circuit. One such circuit is shown in Fig. 3. It will be noted that a pentode electrometer valve is employed in a d.c. amplifier circuit with overall negative feedback to the load resistance $R_L$. With this circuit input impedance and hence response time are divided by the amplifier gain. Other advantages which accrue from this more elaborate circuit arrangement is that dependence on voltage stability is reduced, and the value of the guard ring is increased. One other feature which is worth noting is the use of a guard ring on the range switch for switching different load resistors into the measuring circuit. The usual arrangement is shown in Fig. 4, whereby resistors not in the circuit are grounded and switch leakage does

Double ionization chamber with the chambers arranged in opposition so that the current from the collector gives the beta-dose only (Fig. 2)

not shunt the selected input resistor between the grid and the feedback line.

Figure 5 shows the type of circuit (6) used for wide-range measurement of dose-rate. A pentode electrometer is employed in which negative feedback is applied to the screen grid. The anode current is maintained substantially




A d.c. amplifier circuit using a pentode electrometer valve gives a much shorter response time than the circuit in Fig. 1 (Fig. 3)

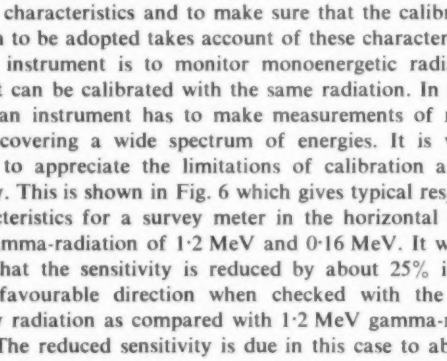
constant over the operating range of the system. Selected valves can be used in this circuit to cover up to seven decades, e.g. $10^{-13}$ to $10^{-6}$A.

## Mechanical arrangements

Survey meters require a careful layout to ensure that a satisfactory performance is obtained. In the case of many health physics instruments good omni-directional characteristics are necessary over the required solid angle of detection. This is important not only in connexion with the overall performance of the apparatus, but also with its calibration. In most cases good omni-directional characteristics are required over the forward $2\pi$ solid angle. Instruments of this type are, however, invariably calibrated using a point source (usually radium or radio-cobalt) and it is necessary that the calibration method adopted takes account of the manner in which the apparatus is normally used. If this is not done gross errors can result.

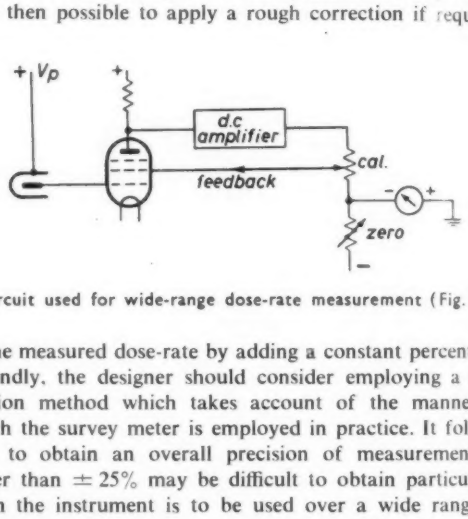
In general, it is necessary when designing survey meters to have a complete knowledge of the instruments' directional characteristics and to make sure that the calibration system to be adopted takes account of these characteristics. If an instrument is to monitor monoenergetic radiation, then it can be calibrated with the same radiation. In many cases an instrument has to make measurements of radiations covering a wide spectrum of energies. It is worth while to appreciate the limitations of calibration at one energy. This is shown in Fig. 6 which gives typical response characteristics for a survey meter in the horizontal plane for gamma-radiation of 1·2 MeV and 0·16 MeV. It will be seen that the sensitivity is reduced by about 25% in the least favourable direction when checked with the low-energy radiation as compared with 1·2 MeV gamma-radiation. The reduced sensitivity is due in this case to absorption in the battery compartment which is at the back of the meter. The reduced performance is limited to a very narrow angle (about 20°) while the solid angle involved is about 7% of $4\pi$. The correction will therefore be very small when concerned with a source giving rise to equal dose-rates over the lower $2\pi$. It will be less so when concerned with a source giving rise to equal dose-rates over the forward $2\pi$. Generally it follows that the ionization-chamber detector should be arranged forward of the rest of the apparatus and arranged so that as small an angle as possible is obscuring the direct view of the contamination by the detector.

In this guard-ring arrangement load resistors not in the circuit are grounded (Fig. 4)




It is also worth remembering that when instruments are carried by an observer his presence near the instrument may influence the reading. This is shown in Fig. 7, the outer curve corresponding to the measured performance without an observer in close proximity to the instrument. In general it is found that the presence of the observer causes a reduction in the measured dose-rate by 10% to 15%.

Two points of special interest to the designer arise. Firstly, he should plan the layout of his instrument so that the two curves of Fig. 7 are as symmetrical as possible. It is then possible to apply a rough correction if required




Circuit used for wide-range dose-rate measurement (Fig. 5)

to the measured dose-rate by adding a constant percentage. Secondly, the designer should consider employing a calibration method which takes account of the manner in which the survey meter is employed in practice. It follows that to obtain an overall precision of measurement of better than $\pm 25\%$ may be difficult to obtain particularly when the instrument is to be used over a wide range of gamma-ray energies. It is, of course, possible to arrange the detector head on the end of a metal tube held at some distance in front of the observer. With the detector head at about 3 ft in front of the observer a precision of measurement of dose-rate over an energy range of 65 keV to 2 MeV has been obtained with a number of designs based on this principle even for widely dispersed contamination.

Another design aspect to bear in mind in designing survey meters is that the provision of a beta-window in an ionization-chamber inevitably affects the performance of the composite instrument when used with gamma-radiation. Hence, when reasonably high precision is required it is a good plan to avoid an all-purpose ionization-chamber. It is better to have separate ionization-chamber heads, one for gamma-radiation measurements and a second one for beta-radiation measurements.

It should be noted that the provision of a beta-window in an ionization-chamber does no more than ensure that the instrument is sensitive to beta-radiation, and it does not follow that the instrument can be used quantitatively. If the window is limited to one side of the chamber (as is usually the case) then the instrument will exhibit marked

directional characteristics. This limitation should be made known to the user, who otherwise can obtain false confidence in the results he obtains with it.

To calibrate a survey meter for beta-radiation it is necessary to compare the readings obtained with an extrapolation chamber, which allows a true assessment of the beta-ray dose-rate to be made. Measurements with typical instruments of the type mentioned above (with a beta-window on one side of the chamber) show that it is necessary to multiply the measured deflection by a factor varying between 10 and 30, depending on the energy of radiation, to obtain the true beta dose-rate. With mixed fission products the higher ratio can be neglected because of the greater proportion of very hard beta-radiations (1·5 to 3·5 MeV), and it is then reasonable to say that the readings taken with the survey meter with an extended fission product source would give a reading of 1/10 that of the true beta-ray dose-rate. This factor will vary somewhat according to the size and shape of the beta window, the factor being larger with a smaller window. However, with a typical instrument with a window on one side of the chamber a ratio of 10/1 in $\beta/\gamma$ dose-rate would appear as equal deflexions on the instrument. As a beta dose of 10 rads is no more serious than a gamma dose of 1 rad a reasonable impression of the beta hazard is given by an instrument of this sort. It may be noted that a beta hazard comparable with the gamma hazard would cause a doubling of the deflexion on removing the cover plate to expose the beta-window.

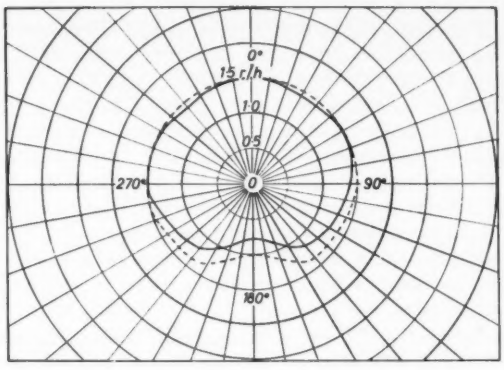
### Counter dose-rate monitors

As already mentioned, geiger counters can be employed as detectors in dose-rate monitors, but such instruments are not as versatile as the corresponding ionization-chamber monitors. They can be designed to use transistor rate-meter circuits and can consequently be constructed in a compact, light-weight form. Their main application is for rapid survey work in detection and location of spills and contamination.

Monitors using scintillation counters may be employed for the measurement of dose-rate. Organic and inorganic scintillators with high efficiencies are available for gamma-detection and measurement of low gamma-ray fluxes is possible using these scintillators in association with photo-multipliers. Thallium-activated sodium iodide scintillators are often used for gamma-ray dosimetry (*7*). They have the advantage of offering high detection efficiency and good energy resolution, but the disadvantages are that their energy response is not tissue equivalent (due to the presence of high atomic number constituents) and that they respond to fast neutrons. Plastic scintillators have also been employed for gamma dosimetry (*8*) as have anthracene scintillators. They have the advantage that they provide a response to gamma-radiation similar to that of body tissue regardless of energy, but both these scintillators have a high neutron detection efficiency which limits their application to gamma dosimetry.

### Neutron survey meters

The r.b.e. of neutrons is very dependent on their energy. An assessment of the neutron exposure, therefore, involves the measurement of the flux and the energy distribution. When only slow neutrons are present, ionization chambers or counters filled with $BF_3$ gas or lined with elemental boron may be employed. Neutron capture by B-10 results in the emission of an alpha particle and the resulting




Typical response characteristics of a survey meter in a horizontal plane to gamma radiation (Fig. 6)

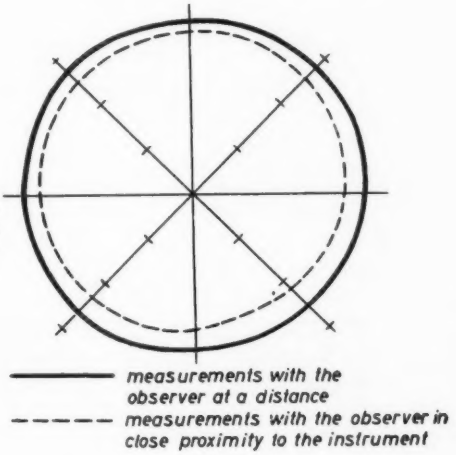
ionization may be collected as a measure of the neutron flux, or the detector may be operated as a proportional counter. The latter system allows the detector to operate even in the presence of strong beta- and gamma-ray backgrounds.

Fast neutrons may be measured using recoil proton counters (*9*) but neutron detection efficiencies are low. Scintillation methods have also been employed. Europium-activated lithium iodide phosphors have been used, but have the disadvantage of responding also to neutrons and gamma radiation.

Recently health monitors have been proposed (*10*) depending on the methods of discriminating between neutrons and gamma-rays proposed by Brooks (*11*) and Owen (*12*). The proposal is to employ an organic scintillator, e.g. anthracene which shows an effectively longer scintillation decay for protons (recoil protons from neutron interactions) than for electrons (Compton electrons due to gamma-radiation). This makes it possible to detect fast neutrons in the presence of gamma radiation. Fast neutron efficiencies of the order of 10% are possible with a gamma efficiency of less than 0·007%. It is also possible to use similar equipment in association with an anti-coincidence circuit to monitor only the gamma radiation, and instruments of this sort are under development (*13*).

### Personnel monitoring instruments

Estimation of the degree of blackening on photographic film is often used for the determination of total dose, but



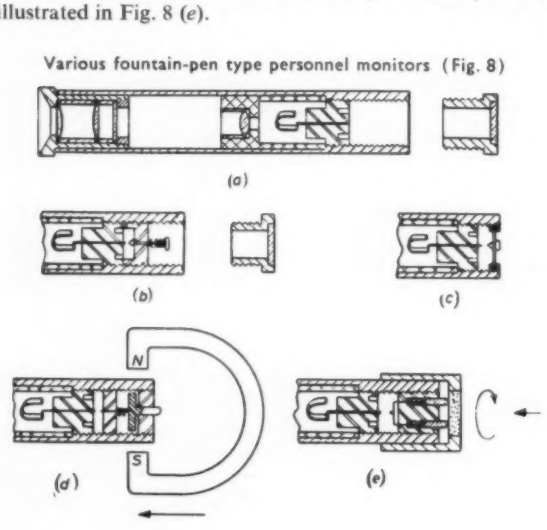

The effect on the measured dose of an observer close to the instrument (Fig. 7)

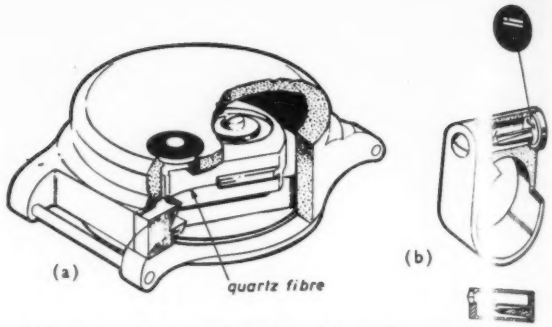
the most popular instrument for this type of measurement is the quartz-fibre dosimeter. This comprises a small ionization chamber to the inner electrode of which is attached a small gilded quartz fibre in the form of a hair-pin movement. When the instrument is charged the quartz-fibre movement takes up some standard position corresponding to the zero of the scale observed with the optical system incorporated in the instrument. Exposure of the instrument to radiation causes the charge to leak away with a consequent change in the deflection of the quartz-fibre movement, so that the change of deflexion at any time gives a measure of the dose received.

Suppose that $V_1$ = initial potential difference across chamber in volts, $V_2$ = potential difference across chamber after exposure also in volts, $C$ = electrical capacitance of chamber in farads, $V$ = air volume of chamber in cm³. Then it follows that the initial charge stored in the system $= CV_1$ coulombs. The loss of charge after exposure will be $CV_1 - CV_2 = C(V_1 - V_2)$ coulombs. Hence the dose received will be $= 3 \times 10^9\, C(V_1 - V_2)/V$ roentgens.

Instruments of this type can be made very compact and often are similar in size and shape to a fountain pen and so can be carried conveniently in the pocket. Several designs (*14, 15*) are illustrated in Fig. 8. Figure 8 (*a*) is the simplest form with a removable end cap for charging purposes. One of the difficulties with this simple form of instrument is that the quality of insulation may deteriorate during use on account of the insulator becoming contaminated with dust, moisture, etc., during the time the end cap is removed. This difficulty is avoided to some extent in the designs illustrated in Fig. 8 (*b*) and (*c*). In the former design two insulators are employed, the main one carrying the inner electrode of the ionization chamber and the second one a spring-loaded connexion piece which is pressed in contact with the electrode only during the instant of charging. With this system the low-leakage characteristics of the instrument are much easier to maintain throughout use. The method illustrated in Fig. 8 (*c*) uses a flexible diaphragm, has the merit of being somewhat simpler, but has been found to be less satisfactory mechanically. Fig. 8 (*d*) illustrates another method in which electrical connexion with the inner electrode is made by magnetic means. It is also possible to incorporate in the dosimeter its own frictional charger. This system is illustrated in Fig. 8 (*e*).

Various fountain-pen type personnel monitors (Fig. 8)




Two types of personnel monitor. (a) can be worn as a wrist watch, and (b) fits on a finger (Fig. 9)

The fountain-pen type of instrument is very popular, but there are other types which have special advantages in certain circumstances. Two such designs are shown in Fig. 9. With such a small instrument charging becomes a problem. The method adopted in this design is to employ the corona discharge from a sharp point to transfer the charge to the highly insulated electrode system. In both cases it is possible to incorporate in the chamber wall a thin window to permit the entry of beta-particles into the sensitive volume. It is thus possible to measure the beta dose as well as the gamma dose with this class of dosimeter.

When reading quartz-fibre dosimeters it is necessary to hold the instrument up to a source of light. For some purposes this is inconvenient and a meter deflecting instrument is required. It is then necessary to replace the quartz-fibre electrometer with a thermionic valve circuit. Many instruments of this type are employed in laboratories and workshops where it is satisfactory to monitor the radiation dose received at one location as representative of that received by a group of workers.

In this class of instrument (*16*) a capacitor $C$ replaces the load resistor $R_L$ of Figs. 1 and 4. Then $V = \int I\,dt/C$. A dose of one roentgen will by definition produce $2{\cdot}08 \times 10$ ion pairs/cm³ at NTP in air so that

$$V = 3{\cdot}3 \times 10^{-10} \times \text{dose} \times \text{volume}/C.$$

It will be appreciated that a switch is needed to discharge the capacitor after making a measurement. The capacitor (and associated ionization chamber) is normally isolated from the measuring circuit and connected only when a reading is taken.

In some cases it is necessary to measure the radiation dose over an extended range. This is usually accomplished by stepping a digital register every time the capacitor charge reaches a level equivalent to an appropriate unit of dose, simultaneously discharging the capacitor.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**Correction**

In the first article of this series, NUCLEAR POWER, April, p. 148, the second column of item 3 in the table should read 'Monitoring of air in reactor buildings and general site area'. In Fig. 1 the shading implies that the monitors at various points are portable, they are in fact installed instruments.

Reactors

*A graphical method of computing total gamma power output and total beta plus gamma power output is outlined*

# U-235 fission product decay energy

*by I. J. MACBEAN, B.Sc. Atomic Energy Establishment, Winfrith*

SUPPOSE THAT a large number of U-235 atoms undergo fission simultaneously through thermal neutron bombardment, and consider the energy radiated subsequently through electrons or gamma emission from the radioactive fission-products and their descendants.

$g(t)$ MeV/fiss.s and $b(t)$ MeV/fiss.s respectively denote the average gamma and beta power outputs per fission at time $t$ after the fissions took place.

$G(t) \equiv \int_t^\infty g(t)dt$ MeV/fiss and $B(t) \equiv \int_t^\infty b(t)dt$ MeV/fiss

may be respectively interpreted as the average gamma-energy and beta-energy residues which will be released subsequent to time $t$.

Alternatively, f. $G(t)$ MeV/s and f. $B(t)$ MeV/s are the gamma and beta power outputs respectively at time $t$ after the cessation of an infinitely long continued irradiation at the steady rate f fiss/s.

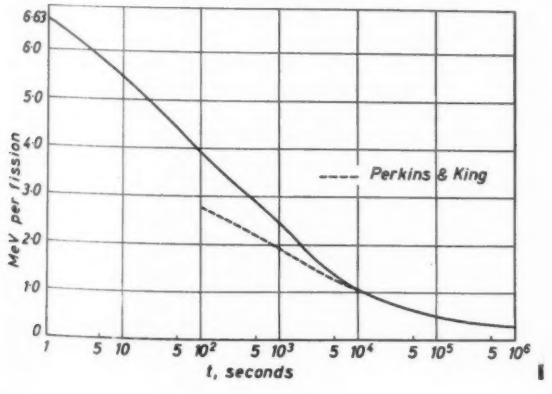
$m(t) \equiv g(t) + b(t)$ and $M(t) \equiv G(t) + B(t)$

$\nu(t)$ MeV/fiss.s is defined as the average power carried away by neutrinos at time $t$ after simultaneous fissions.

During the operation of a reactor each fission leads to the formation of two fission-product atoms of intermediate mass. These are generally highly unstable and they decay through a chain of radioactive descendants with the emission of electrons, neutrinos, and gamma rays until a stable isobar terminating the chain is formed.

The electrons are mostly absorbed in the material close to their source and cause local heating. Although the gamma rays are much more penetrating, they are absorbed mainly in the materials composing the interior of the reactor, and especially in the fuel, their energy being converted to heat. Since neutrinos have extremely weak interactions with matter, the majority will escape into the cosmos, a few being absorbed in the earth's interior.

Fig. 1 Gamma energy residue G(t), from t = 1s to t = $10^6$ s




Of the total heat output of a reactor during steady operation, about 6% is due to the absorption of the radiation from fission-products. The evolution of heat from fission-product radioactivity continues after reactor shut-down, but diminishes by about one decade during the first day (Fig. 3).

With a power reactor, fission-product heat evolution is quite substantial and necessitates the maintenance of adequate cooling for a long time after shut-down. In addition, fission-products may constitute a biological hazard should they escape from the reactor system.

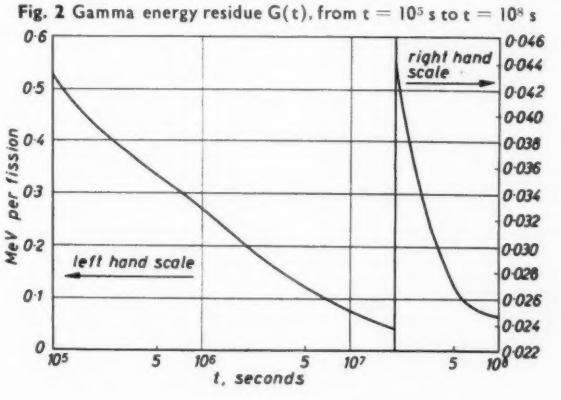
The composition of mixed fission-products is somewhat changed in a high-flux reactor as a result of transmutations induced by neutron capture, but this has little effect on the power outputs $g(t)$ and $b(t)$ of the aggregate, except perhaps at long cooling times $t$, when only a few individual fission-products contribute. Blomeke and Todd (*1*) have calculated these effects, but they have neglected neutron capture in the many isotopes for which the capture cross-sections are unknown.

## Gamma energy release

If the disintegration data of all radioactive fission-products were known, the average gamma power output $g(t)$ could be calculated by summing the radiations from all the fission-products produced during any period of irradiation. However, for many of the shorter lived fission-products, the detailed branching of the decay schemes is unknown. At long decay times, their contribution to the radiation from the gross fission-product mixture is negligible, so that for decay times $t \gtrsim \frac{1}{4}$ day, earlier calculations of the gamma power such as those by Blomeke and Todd (*1*), Howlett *et al.* (*2*) and Burris and Dillon (*3*), are still quite reliable.

The recent calculations by Perkins and King (*4*), using

Fig. 2 Gamma energy residue G(t), from t = $10^5$ s to t = $10^8$ s



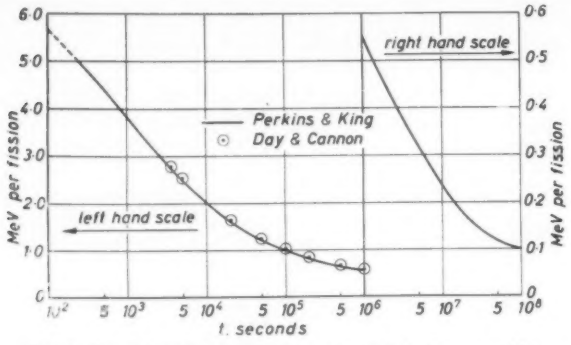



**Fig. 3** Total absorbable energy residue M(t), from $t = 10^2$ s to $t = 10^8$ s

the most recent nuclear data, evaluate g($t$) reliably over the interval $t = 10^4$ s to $t = 6 \times 10^7$ s. Their genetic equations are inexact, but they claim that the resulting errors are trivial. Where information on a decay scheme was lacking, they made theoretical estimates which are probably adequate for the calculation of m($t$), but the separation of beta and gamma powers is unreliable at time $t$ less than an hour. Perkins and King ignored fission-products whose half-lives are $<$ 1 min and those whose half-lives are unknown, so that their calculations are unreliable at times $t$ of less than a few minutes.

Blomeke and Todd (*1*) used rather older nuclear data for their elaborate calculations. Moreover, they assumed that all the nuclides for which the decay schemes were completely undetermined experimentally were 100% beta emitters, ignoring possible beta–gamma branching. In consequence, m($t$) and more particularly g($t$) are underestimated at times $t$ less than a few hours.

The calculations of Burris and Dillon are for fast fission of U-235, and the chain yields used are somewhat different from those for thermal fission. Their results are represented by crude, semi-empirical formulæ and are unreliable for cooling times $t$ of less than 2 or 3 hours.

For short times after fission (1 s to $\frac{1}{2}$ h) we must rely on direct experimental observation of the gamma emission rates from mixed fission-products. The only reliable experimental data are those of Maienschein (*5*) and Zobel (*6*). These data were obtained using three experimental techniques, so that several distinct estimates of the gamma power output are possible.

The function g($t$) calculated from the experimental observations in the interval $t = 1$ s to $t = 1{\cdot}6 \times 10^3$ s was smoothed into the function g($t$) calculated by Perkins and King (*4*) from $t = 10^2$ s to $t = 6 \times 10^7$ s. G($t$) was obtained by integrating this composite curve and by adding the small contribution for $t > 6 \times 10^7$ s which is obtained sufficiently accurately from the somewhat older calculations of Howlett *et al.* (*2*). Finally, to estimate the total gamma-energy residue from $t = 0$, it was necessary to make a small extrapolation over the range $t < 1$ s.

The results of the calculations indicate that the average gamma energy residue subsequent to fission is 7·0 MeV/fiss with an uncertainty of about $\pm$ 1 MeV/fiss. Figures 1 and 2 indicate the gamma energy residue G($t$) as a function of the time $t$ after fission.

## Beta energy release

No direct experimental data are available for b($t$) or B($t$) for mixed fission-products. However, calorimetric measurements of M($t$) have been reported by Untermyer and Weills (*7*) and by Day and Cannon (*8*). The latter measurements have been corrected by Stehn and Clancy (*9*) for the energy carried away by gamma radiation which escapes absorption, and for the heat generated by the decay of U-239 and Np-239.

The average beta-energy emission rate b($t$) has been calculated by Perkins and King (*4*) in the interval $t = 10^2$ s to $t = 8 \times 10^7$ s. The energy residue B($t$) can be obtained by integration and by adding the contribution for $t > 8 \times 10^7$ s from Howlett *et al.* (*2*).

Figure 3 is a plot of the total absorbable energy M($t$) as a function of the time $t$ after fission, for the interval $t = 10^2$ s to $t = 10^8$ s. It shows the excellent agreement between the corrected measurements of Day and Cannon (*9*) and the calculations of Perkins and King (*4*), which extends down to the shortest times $t = 1$ h for which the measurements were made. Taken in conjunction with the comparison of Fig. 1, it appears that these authors underestimate g($t$) and overestimate b($t$) for $t < 10^4$ s. This would imply that $\nu(t)$ is overestimated so that b($t$) + g($t$) itself is likely to be slightly underestimated at short times.

## Average total decay energy of fission products

The total energy from the decay of a chain of fission-products can be estimated from the difference between the exact ground-state masses of the initial and final members of the chain. The initial member is nearly always highly unstable and hence short-lived, so that its mass can only be determined by a rather crude, semi-empirical calculation. This was the basis of the early calculations by Way and Wigner (*10*).

A calculation using more sophisticated mass estimates (*11*), in which allowance is made for the effects of nuclear shell closure, and recent data on chain yields and independent yields leads to a result for the average energy per fission evolved through fission-product decay, which is

$$E = 21{\cdot}15 \pm 0{\cdot}35 \text{ MeV}$$

The uncertainty quoted accounts only for the difference between two independent estimates of the fission-product masses and makes no allowance for systematic uncertainties, which are unlikely to exceed 2 MeV. This result is surprisingly close to the much earlier estimate by Way and Wigner (*10*) namely 21·5 $\pm$ 3 MeV/fiss.

## Some conclusions

The total gamma-energy release, G(o), subsequent to fission was found to be 7·0 $\pm$ 1 MeV/fiss. That leaves $14{\cdot}1_5 \pm 2{\cdot}3$ MeV/fiss which is carried off by beta and neutrino radiations. The neutrino, which has zero rest mass, will certainly carry off rather more than half of this energy; (60 $\pm$ 3) % is a reasonable estimate since most of the energy will come from the energetic short-lived transitions.

We may expect that the average total decay energy is divided approximately as follows: gamma radiation, G(o) 7·0 $\pm$ 1 MeV/fiss; beta radiation, B(o) 5·7 $\pm$ 1·0 MeV/fiss; neutrino radiation 8·5 $\pm$ 1·4 MeV/fiss, so the average total absorbable energy, M(o) is 12·7 $\pm$ 1·3 MeV/fiss.

## Use of the graphs

Given the irradiation time $I$ and the decay time $t$ in seconds, it is simple to compute the following quantities (*2*).

*Gamma power output* For the total gamma power output of the gross fission-products, compute the function

$$G(I, t) = \frac{G(t) - G(I + t)}{I} \text{ MeV/fiss. s}$$

using Fig. 1 or Fig. 2. This relation is valid for a uniform fission rate during irradiation.

*Beta plus gamma power output* Similarly for the total beta plus gamma power output compute the function

$$M(I, t) = \frac{M(t) - M(I + t)}{I} \text{ MeV/fiss. s}$$

using Fig. 3.

The beta power output alone is simply

$$B(I, t) = M(I, t) - G(I, t) \text{ MeV/fiss. s}$$

The total energy release from fission in a thermal reactor is about 200 MeV/fiss. Hence, after a period of steady irradiation, an energy output from fission-products of 1 MeV/fiss may also be written as

0·005 watt fiss prod. power/watt reactor power,

where the power production in numerator and denominator relates to the same unit of fuel.

Details of the calculations and a full bibliography are contained in (*12*).

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Instrumentation

*Problems which arise in field instrumentation for dose measurement are surveyed and several tentative suggestions are made to extend the range of existing techniques*

# The measurement of neutron dose

*by ARNOLD CLARE, B.Sc., Electronics Division, AERE, Harwell*

THE LIMITATIONS of some techniques for measuring neutron doses can probably best be appreciated from a familiarity with the factors which determine the maximum permissible flux (m.p.f.). Also it is convenient to split the neutron energy into three ranges (*a*) slow (thermal to about 10 keV), (*b*) fast (10 keV to abont 30 MeV), and (*c*) high energy (above 30 MeV).

## Derivation of the m.p.f.

In the absence of direct quantitative experience of neutron irradiation of man the m.p.f. is determined by the product of the energy absorption by unit mass of tissue and the relative biological effectiveness (r.b.e.). The energy absorption arises from either inelastic collisions (including absorption) or elastic collisions. For instance in the slow region the inelastic collisions hydrogen-1(n,$\gamma$)hydrogen-2 and nitrogen-14(n,p)carbon-14 predominate, while in the fast region elastic collisions with hydrogen are most important. The dimensions of the human body are large compared to the neutron mean free path so the effect of the back-scattered flux is important. Therefore in the calculations (*1–5*) the body is replaced by a semi-infinite phantom of the same chemical composition as soft tissue (by weight H 10%; C 12%; N 3%; O 74%). The r.b.e.'s for different ionizing particles are given by the I.C.R.P. (*6*); however the contribution from each type of particle varies with depth beneath the surface so the values of the r.b.e. given in Table 1 refer to the position where the rem dose is a maximum. Table I also shows the m.p.f. for occupational exposure (maximal dose in body 300 mrem in 40 h).

These fluxes refer to the undisturbed radiation field and are taken to hold irrespective of the direction in which the neutrons are incident on the body. Some, only, of these values have been officially recommended (*6*). There are no official recommendations above 10 MeV.

**TABLE I** *Values of the r.b.e. referred to the position where the rem dose is a maximum*

| NEUTRON ENERGY | m.p.f. | r.b.e. |
|---|---|---|
| thermal | 2000 | 2·8 |
| 10 eV | 2000 | no information |
| 100 eV | 1550 | 2·2 |
| 5 keV | 1700 | 2·4 |
| 0·02 MeV | 850 | 5 |
| 0·1 MeV | 200 | 9 |
| 0·5 MeV | 80 | 10 |
| 1·0 MeV | 60 | 10 |
| 2·0 MeV | 40 | 10 |
| 3 to 10 MeV | 30 | 10 to 11 |

## Tissue equivalent methods

The energy absorption in tissue may be derived from the current in tissue equivalent chambers. To maintain tissue equivalence over all neutron interactions then the chemical composition of the chamber must be the same as soft tissue. For fast neutrons only, polythene is a suitable material. In addition one tries to simulate the irradiation geometry of the body by using phantoms or applying a numerical correction for the back-scattered flux. Such measurements can, in principle, be made in any energy range, but for slow neutrons there are practical difficulties because of sharp changes in the spatial distribution of the energy absorption. To measure the dose the r.b.e. must be known and adequate prior knowledge of the neutron spectrum seldom exists for one to choose the correct r.b.e. from Table 1. The $\gamma$ quanta, which always accompany neutrons, also affect the r.b.e. and their presence is allowed for by using a second chamber of different neutron to gamma sensitivity. The difference between the currents of the two chambers is then a measure of the neutron dose. The significance of such a difference method is sensitive to the precision of the compensation, particularly in the fast region, where for a given rem dose of neutrons the current in the tissue equivalent chamber is only about 1/10 of that due to an equal dose of quanta. Thus the problem with current measurements is one of deciding the appropriate r.b.e.

In two instances operation in the proportional region helps to reduce the ambiguity. The first (*7*) eliminates the $\gamma$ sensitivity by biasing off the small $\gamma$ pulses and then in fast neutron irradiation measures the energy absorption from recoil protons for which an r.b.e. of 10 is taken. The second (*8*) uses a spherical counter in which the path lengths are such that from the pulse spectrum one can deduce the incremental energy absorption and the specific ionization with which that increment occurs. It has been demonstrated for fast neutrons. Extension to other neutron energies when ionizing particles other than protons contribute to the dose has not yet been demonstrated, but it offers the possibility of providing semiquantitative in-

formation about the r.b.e. without invoking knowledge of the composition of the radiation field. As such it is a powerful technique.

### Controlled sensitivity

This is the second class of dose measurement in which the sensitivity is made inversely proportional to the m.p.f. This method tends to offer a simpler and more direct reading type of instrument. It has the disadvantage that a given instrument only maintains an adequate degree of proportionality over a limited energy range, so in a wide spectrum one is faced with the difficulty of using several detectors with overlapping energy ranges.

### Slow neutrons

Table 1 indicates that a desirable detector should have a constant sensitivity; progress in this direction may be judged with the help of the following tentative suggestions.

First thermal neutrons. A thin '$1/v$' detector gives a response proportional to the neutron density. Thus the dose calibration is temperature sensitive to the extent that if the detector is calibrated in a known flux at temperature $T_1$°K and then used in a flux at a higher temperature $T_2$°K the dose will be underestimated by $(T_2/T_1)^{\frac{1}{2}}$ since the dose is proportional to the number of neutrons entering the body. A reaction which is almost equally efficient for thermal neutrons of all velocities is capture in cadmium. Also, if the cadmium is sufficiently thick to capture all the neutrons, then the capture $\gamma$ data (*9*) shows that a sheet exposed to a 1 rem beam of thermal neutrons, will emit in a given $2\pi$, approximately 1 rem of $\gamma$ quanta. Thus the possibility exists that a $\gamma$ dosimeter shrouded in cadmium would measure the thermal neutron and extraneous $\gamma$ dose correctly.

In the epicadmium region energy selective measurements are extremely difficult. A reaction which approximates to the ideal is fission of U-235 after some of the neutrons have been absorbed in 1 g/cm² of pure B-10 (Fig. 1). A useful instrument would be a fission chamber using this reaction. A dose interpretation in a wide spectrum would involve a fast neutron dosimeter since the cross-section extends to the MeV region.

The fission reaction has a threshold of 100 eV. Measurements (*10*) between 100 eV and the cadmium cut-off energy depend upon choosing an isotope which has one predominant activation resonance in this region and assuming that the induced activity is entirely due to this one resonance, then the differential distribution of the neutrons at the resonance energy may be found. The dose is derived by using several materials to plot a coarse spectrum.

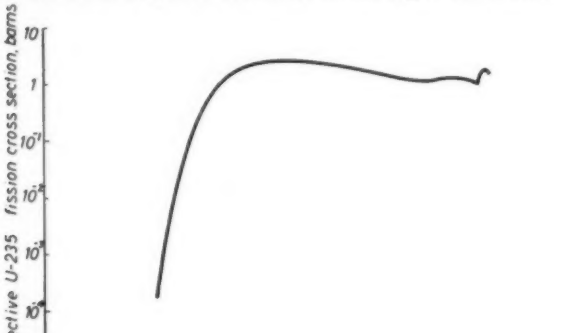


**Fig. 1** Fission cross-section after neutron absorption in B-10

### Fast neutrons

Non-directional recoil proton proportional counters have been demonstrated (*11, 12*). The lowest neutron energy is determined by the bias energy which cannot be decreased below about 0·1 MeV without undue sensitivity to $\gamma$ quanta. The highest energy at which the counters have been shown to be adequate is 14 MeV. The response above 14 MeV is difficult to predict because of competing processes but the sensitivity will probably fall below that demanded by the dose. There will be no sharp cut-off. The efficiency of the proton radiators is limited, so the sensitivity is determined by the projected area of the counter. Nuclear emulsions are also used in this region (*13*).

### High energy

Radiological measurements around high energy accelerators is a subject in which relatively little experience exists. Difficulties may be anticipated from the fact that when a beam of high energy neutrons (or protons) traverses a shield the composition (in terms of energy and types of particles) of the emerging beam depends on the shield thickness. This would seem to indicate the technique (*8*) which is least dependent on prior knowledge of the radiation. Adequately safe measurements would be obtained from tissue equivalent chambers in a phantom using an r.b.e. of 10. At AERE the carbon-12(n2n)carbon-11 and carbon-12(ppn)carbon-11 reactions have been used to measure small fluxes of nucleons (*14*).

### Pulsed sources and criticality

Many techniques involve gaseous detectors employing charge collection and reservation should be maintained regarding their use with intermittent radiation of high peak intensity. In pulse counters the shortest permissible time between events is determined by the rise time of the leading edge at the collection electrode. In practice the time may be longer due to recovery time in the recording circuits. It is not possible to generalize and each case should be treated individually. The analogous problem in the case of current measurements is one of recombination (*15*). Probably the best overall check against malfunctioning of this kind is to note whether, for a given duty cycle, the response is proportional to machine output.

If the detectors are thereby shown to be unusable the only technique which has been demonstrated is that of threshold reactions (*16, 17*). The object is to construct a neutron histogram by spacing the thresholds. A fundamental difficulty is, that due to the shape of the activation cross-section, the neutron spectrum enters explicitly into the determination of the effective cross-section. The least ambiguity probably arises when an intuitive guess at the spectrum is duly modified to maintain consistency between the observed reaction rates. Other features to be noted are the very low sensitivity, and the precautions against interfering reactions. Many points in this article are covered in greater detail in (*18*).

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# Cross Section by GRACCHUS

STORIES about travelling salesmen are legend and, I thought, taken with a liberal pinch of salt. But it appears that I have been wrong. I was staggered to learn when listening to Sir Walter Warboys at the annual conference of Production-Engineering Limited at Oxford, that not only were some British firms not yet convinced that exports were worthwhile but some 'still believe that it is wrong to expose young British salesmen to the temptations which our Victorian forebears were convinced were associated with Continental travel!' I trust the Board of Trade's new Export Publicity Council will take due note.

MEMBERS of the Nuclear Engineering Society must have been cheered by the optimistic tone of Sir Roger Makins' address at their twelfth annual dinner. He told members that Britain had built up resources and skills in nuclear power which were needed now and would surely be needed more abundantly. 'My task', he said, 'is to see that these resources are husbanded and conserved and are available for the day when they will surely be needed'. Sir Roger also made the telling point that though early hopes had not materialized, he was not depressed for no prediction he knew about raw materials had ever been right after 2/3 years. He had very little doubt that the pendulum would swing back again.

JOHN THOMPSON engineers engaged on nuclear power projects had, I estimated, a chat of about 15 minutes with the Duke of Edinburgh when they were presented at the company's film show and cocktail party at Grosvenor House. Introductions had been performed by the company chairman, Sir Edward Thompson. The two films featured the activities of John Thompson companies in the building of Dounreay and Berkeley with a supporting photographic display showing the many uses of John Thompson industrial equipment.

CANADIAN URANIUM MINERS have been looking wistfully at the 1959 profit of £A3,750,000 announced by Mary Kathleen Uranium. This, Australian friends tell me, emphasises the large earnings possible in the uranium mining industry, for the company's returns in little more than 18 months operation have been worth more than £A5 million. Their attitude is in decided contrast to that of the Canadians who believe that the bottom has dropped out of the world uranium market, at least where Canada is concerned. I understand there is already talk that some mining towns, including the largest at Elliot Lake, will, before long, be turned into ghost towns. If this happens we may see in the advertisement columns of Canadian papers uranium mining and processing equipment being offered as 'atomic age bargain basement specials'. The last, and I believe the first, time an advertisement like that appeared was in April last year when the University of Chicago advertised in the 'For Sale' columns of various newspapers, the 100 million volt electron accelerator put into operation by the late Dr. Enrico Fermi in 1950.

IT'S PLEASING to hear that a Harwell committee have launched a scheme for bringing a refugee family to this country. I understand that this plan was evolved as part of Harwell's support for the International Refugee Year and that the immediate object is to raise £2500 by subscription from research station members. Once the money has been raised and the family chosen, housing will be found near the station. The idea behind this is to provide its members with a sense of belonging to the community and also to find a job for the head of the family, possibly in some non-secret capacity, at Harwell. It seems likely too, that the AEA will help with some parts of the plan.

I LIKED the way Lord Hailsham has stamped on the traditional ploy of cartoonists and humourists—the impractical, absent-minded professor—which has tended to be accepted as general by many. My notes of his speech at the Royal Institution of Naval Architects' annual dinner show that it was not only the general public that held this view, for Lord Hailsham quoted Sir James Graham, First Sea Lord in 1832 and 1854 as saying there was 'too much science and too little practical knowledge creeping in the Navy'.

Lord Hailsham commented: 'Our country is still too apt to suppose that the scientist is an unpractical egghead and that the man who proceeds by trial and error is the man to trust. There is no fallacy in this island more universally believed than that the man with brains is not to be trusted. Either, so it is thought, he is unpractical or he is wicked, and in either event we must not allow science to supercede practical knowledge.' Sir James Graham was wrong, added Lord Hailsham. Science might not be a substitute for practical knowledge, if practical knowledge meant the judgement that was the fruit of experience. But practical knowledge, whatever its meaning, was certainly no substitute for science.

US SCIENTISTS let their imaginations run riot when they predicted future uses for nuclear energy before a hearing of the Congressional Committee on Atomic Energy recently. Likely applications were maintaining outposts on the moon and Mars, clearing smog from cities, exploring and mining ocean beds, using reactors to send TV programmes round the world and turning water and air into fertilizers. While I hardly like the idea of world-wide TV programmes, the idea of clearing smog from cities fascinated me. Apparently the method suggested is for a large nuclear power plant to be built which would heat enough air to drive a hole in the smog over a city.

Further possibilities were explored by Dr. B. I. Spinard of the Argonne National Laboratory. A most exciting future use of atomic energy, he said, was the possibility of using reactors not only for power sources in satellite stations and for electrical propulsion of space ships but, indeed, for setting up of large permanent bases on the moon and Mars. He also foresaw no intrinsic obstacle to building mobile power stations which could be 'flown' to these points.

Another aspect Dr. Spinard touched upon was a 'nuclear machine gun'. This was to be a reactor which would give powerful pulses and be used for the propulsion of space ships or triggering-off chemical reactions on earth.

ONE of those doubtful distinctions has fallen on the county of Cardiganshire. I see that the second report of the Agricultural Research Council's radiological laboratory dealing with strontium fallout places the county first in areas of the country which are subject to the highest levels of fallout.

# Beryllium fabrication in the UK

## first large-scale production

Because of the extreme difficulty in extracting beryllium from the ore and in refining it, the metal has been available only in small amounts since 1945. Four firms are now actively engaged in the production and fabrication of the metal on an industrial scale and facilities for the development of fabrication techniques and for testing beryllium are available at three UKAEA establishments. A fourth facility, which is to be used for the production of fuel elements, is being commissioned.

The UKAEA effort has therefore been devoted to many practical and theoretical problems. A wide range of production, fabrication and welding techniques were examined and assessed followed by the development of arc melting, electron beam melting and new sintering methods. Specific processes such as the extrusion of fine bore tubing to close dimensional tolerances were then exploited. Apart from fabrication, it was necessary to look into the effects of irradiation on the physical, chemical, mechanical and metallurgical characteristics of the metal.

The effect of impurities on the properties of beryllium coupled with the development of new techniques for the production of ultra-pure metal were also studied. Another very important factor examined was the mechanism of deformation of the metal and the preferred orientation of the deformed metal. This has necessarily included heat treatment studies, aimed at improving an understanding of the brittle nature of the metal and ultimately to increase creep ductility.

### Beryllium machining

Apart from the fabrication difficulty caused by brittleness, whilst the beryllium is not in itself dangerous, health hazards are created by the fine dust that is formed, especially during machining operations. The new Armstrong Whitworth Aircraft's factory at Coventry, which started operations in February, is the first large plant of its kind in Britain for machining beryllium, and it has been equipped to cater for the problems created. The initial output of AGR components will be 200 fuel element end caps per hour in addition to the weekly production of 20 thermocouple elements and 200 element support plates.

The factory which covers nearly 20,000 ft² is divided internally into contact areas, where the beryllium is being machined or handled and toxic hazards have to be prevented. The contact area is contained in a pressure shell supplied with filtered and heated air that is changed every three minutes. Air for heating and ventilation enters an induction system where it is preheated and filtered to ½ micron. The air extraction system incorporates Vokes absolute filters which ensure a cleanliness of ½ micron before the air is finally released to the atmosphere through a 125 ft high ventilating shaft. Machining processes are carried out inside completely enclosed machines and the separate extraction systems working at an air velocity of 500 ft³/min remove all swarf and dust at the point of cutting. Swarf is separated out by cyclones and recovered for reprocessing into raw material, after being carefully examined for contamination.

The top limit set for air contamination is 2 microgrammes per cubic centimetre. Until it is found that monitoring results are entirely satisfactory, in the earlier days of cutting beryllium, all operators will wear pressure suits, to be followed later by face masks, and finally specially designed clothing.

In machining operations, each tool is completely enclosed in a glove-box and a secondary extraction system removes all swarf produced within.

In this glove-box lathe operations are being carried out. Beryllium components are removed through a water trap to limit transport of swarf.

# Plotting magnetic fields

## cyclotron evaluation

A magnetic field plotting system for evaluating the detailed performance of a cyclotron before it is built has been developed and placed in operation at the US Oak Ridge National Laboratory, which is operated for the AEC by Union Carbide Corporation. It has cut the time for a given magnetic field configuration to about 36 hours. The apparatus consists of a well-coordinated mechanical and electronic system which automatically programmes and positions a

small probe that provides a voltage signal directly proportional to the strength of the magnetic field. The accuracy of the probe, a thin wafer of semi-conducting material measuring $\frac{1}{32}$ in² area, is further enhanced by the use of a newly developed compensating network that minimizes the effect of temperature variations during the measurements.

An earlier way of evaluating and correcting a magnetic field was to choose the best known magnet design and then, by actual operation of the completed cyclotron, trace the paths of ions outward from the centre. Wherever the ions became lost, a magnet was tailored by grinding or patching until an acceptable performance was obtained. Recent methods of field measurement and orbit computing greatly simplified the problem but it was still a very slow process for complex fields such as those used in the Oak Ridge Isochronous Cyclotron now under construction.

## Radioactive go-devils

### lead pot screening

An ingenious solution to the problem of handling go-devils containing radioactive sources has been developed by Mr. S. Jefferson and Mr. J. C. Daglish of the Atomic Energy Authority and is now patented. Quite simply, the invention provides adequate screening by incorporating a lead pot into the go-devil and ensuring that—by means of a pressure-sensitive device—the radioactive source will stay inside the pot under normal atmospheric pressure and will only be pushed out of its container when the latter is subjected to pressure from a liquid or gas in a pipeline. Should the go-devil have to be recovered, it would be sufficient to reduce the pressure in the line for the source to return to a safe position. The apparatus should be particularly useful for clearing pipelines where thick sludges occur.

## Low cost remote handling

### reduced force by p.t.f.e.

A novel application of remote handling equipment together with the use of p.t.f.e. dispersion has been developed for a pedal-operated mechanism for polio patients. Whilst the principle of operation is similar to that of remote handling tongs, to cut the cost from £1000 down to about £50, expensive servo-mechanisms and special machining operations were avoided and components from standard equipment used wherever possible. Thus the foot controls are connected to the eating utensils by Bowden cables; the 'femur' is an angle-poise lamp bracket; and the 'hand' a car-type crocodile grip.

Whilst it was found that the patient could not exert a force of more than 2 lb, the equipment required a $2\frac{1}{2}$–4 lb force to operate. The problem was overcome by spraying two coats of Acheson resin-bonded dispersion of p.t.f.e., 'Emralon' 820, on all inner cables and the sliding surfaces of the foot control. The force required to operate the mechanism was then reduced from an average of 3 lb down to 2 lb.

## Trawsfynydd flux scanning

### two-wire system

Neutron flux distribution in the Trawsfynydd reactors will be measured by irradiated tungsten wire placed inside a sealed standpipe. The flux scanning heads, designed by Elliott Nucleonics will be interchangeable with the control rod mechanisms, using the same standpipe closure and seal plug. A two-wire system permits the wires to be used alternatively. This is necessary since it takes about one week for the activity of the irradiated wire to decay to less than 1% before it can be used again. The period of waiting is thus reduced to three or four days.

Each flux scanning head uses two identical winding units comprising a winding drum driven by an a.c. induction motor with limit and signalling switches operated by gear trains and cams. The winding drums which are two feet in circumference and approximately $1\frac{1}{4}$ in. wide are helically grooved to accommodate 80 feet of the tungsten wire.

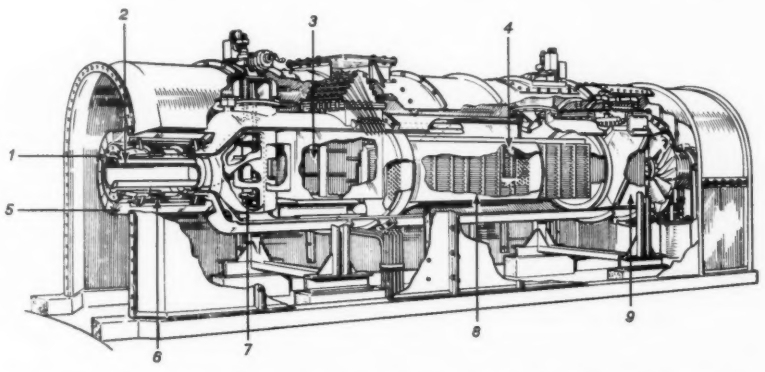
# High temperature gas circuit units

### $CO_2$ blowers for Hero

Under contract to the AEA some interesting equipment is being manufactured by the de Havilland Engine Company for the primary gas circuit of the zero energy Hero reactor.

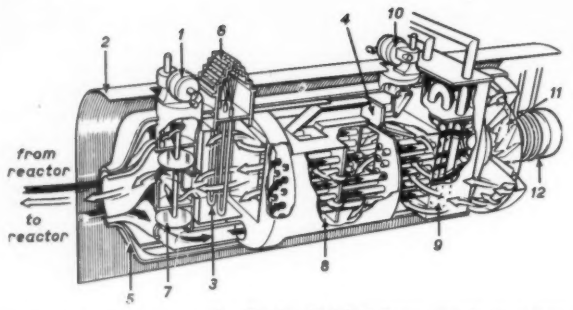
In order to simulate the actual operating conditions of AGR as closely as possible, the core of Hero will be heated by pumping carbon dioxide gas at a temperature of about 500°C through the reactor by two blower units, each with a capacity of 233 lb/min $CO_2$ at atmospheric pressure. One of these is for bulk circulation, blowing the gas through the core and back round the outside of the graphite stack; the other for selective heating of the middle channels.

The two primary gas circuits are identical units connected to the reactor vessel by short annular ducts. Gas flowing from the reactor, passes through the outer annulus of the connecting duct, through the isolating valve and then into the regenerator tubes. The gas is partly cooled by transferring some of the heat to the incoming gas stream and further cooled to about 50–70°C by passing it through a water-cooled heat exchanger situated upstream of the compressor inlet. The gas, after being raised in pressure by about 2·5 lb/in² in the compressor, flows in three passes across the outer surfaces of the tube bank of the regenerator. It is then brought back to operating temperature by an electric heater unit of 450 kW capacity before returning to the reactor through the central duct.




Cutaway drawing of one of the Hero primary gas circuit units showing main components

1 $CO_2$ inlet duct; 2 $CO_2$ outlet duct; 3 electric heater; 4 heat exchanger by-pass valve; 5 heat shield; 6 bellows assembly; 7 isolating valves; 8 heat exchanger; 9 cooler




Simplified drawing showing flow path Carbon dioxide gas from the outer annulus flows through isolating valve (7), is reduced to 50–70°C in heat exchanger (8), which is water cooled (9). It is then recirculated by gas circulator (11), reheated by electric heater (3) and returned to reactor. Other components shown: 1 isolating valve actuator; 2 ventilation hood; 4 heat exchanger by-pass valve; 5 containment vessel; 6 heat terminals; 10 by-pass actuator; 12 circulator motor (water cooled)

The problems introduced by handling gases at high temperatures have therefore been overcome by cooling the gas prior to entering the compressor, and reheating it on the discharge side. The use of beryllium for canning the fuel and the toxicity of the finely divided form made it necessary to reduce leakage in the gas circuit to negligible amounts and, the experience gained in the construction of the hermetically sealed circuits for the Pluto test loop was used to advantage.

## Electric smelting service

### 350 kVA pilot furnace

A pilot smelting furnace is now in operation at Birlec-Efco (Melting) Limited, to promote the development of electric smelting processes by accepting trial batches of customers' raw materials for testing their amenity to electro-thermal reduction and for determining the most suitable smelting technique and the nature of the resultant products. Information can be gained on power and electrode consumption, operating voltage and percentage recovery.

The furnace, with a shell of 8 ft internal diameter is surrounded by a charging platform at a height of 9 ft from the main floor level with the furnace controls suitably housed in a panel adjacent to the furnace operating platform. With a nominal rating of 350 kVA, a wide range of voltage tappings have been provided enabling, as far as is practicable, the whole range of electric smelting applications to be covered. To determine the effect of shell rotation for different smelting operations, the shell can be rotated or oscillated in either direction at varying speeds.

Three tapholes are provided, the levels of which can be altered for slag and metal and they are served by a monorail beneath the platform, forming a loop surrounding the shell. Several thermocouples are built into the refractory lining to monitor the temperature of the hearth and sidewalls at different points.

The furnace is equipped with holders suitable for 8 in. diameter electrodes which can be amorphous carbon or graphite according to the requirements of the tests but smaller electrode holders can be fitted if necessary. The electrode clamps are arranged for remote control.

## Uranium brazing

### argon arc torch

Metallurgy Division at AWRE has invented a brazing torch which uses an intense electric arc to heat a stream of inert gas, mainly argon, to very high temperatures. The torch is so designed that it produces a needle-like jet of intensely hot gas which blankets the surface under treatment and protects it from contaminant gases. The temperature of the 'flame' can be controlled by limiting the power input to the torch.

Other work for which the torch can easily be adapted includes local heat treatment and stress relieving, softening metals for bending and, in short, any process for which an oxygen gas torch would normally be used. The torch was originally designed for use in an argon-atmosphere glove-box but could equally well be used for work on such metals as zirconium, titanium and beryllium. The device could also be used to carry out accurate cutting of stainless steel at high speeds.

## Control rod gear

### woven wire cable

Cables and drums for control rods with their complicated and bulky traversing mechanisms will be done away with. Instead, a 'pancake' winding drum can be used in conjunction with a ribbon of woven wire of nearly the same width—preferably a length of flattened tubular woven stainless steel wire braid. This ensures that lateral movement of the cable will be reduced to a minimum and full utilization of a winding volume which can be appreciably cut. A disadvantage is that such materials tend to stretch under load, but this is easily allowed for as the amount of stretching for a given load is about constant.

The equipment was developed by Mr. L. Hack and Mr. F. O. Cowburn of the Atomic Energy Authority.

## Hinkley fuel charging

### servo-controlled positioning

Fuel charge machines for Hinkley Point weigh up to 155 tons; but their positioning has to be accurate and their movement smooth. The EMB Co. has developed a control system for the travel and traverse motion of the cranes that permits these heavy machines to move over the charge floor without any sudden movement. The 'Microsen' control is arranged to give 11 notches of graduated speeds controlled by a motor-operated servo-controller.

With the deadman's handle depressed, rotation to any notch starts the operating motor which drives the master controller at a predetermined speed until it coincides with the position to which the handle has been turned, the contactors, controlling the travel and traverse motions being operated in the correct sequence, with smooth controlled acceleration. It is impossible to increase the acceleration above the predetermined limit, by any quick movement of the handle.

The EMB motor-operated servo-controller allows accurate positioning of fuel charge machines

The handle can be moved to any predetermined notch, reversed, or moved to any other desired notch, the master controller following and cutting itself out when the desired position is reached. Both the master controller and the motor controlled circuit fingers are cam-operated; the silver-faced contacts being spring applied and mechanically opened.

# *Points from Papers*

*reports, meetings, conferences*

## PROGRESS AT DRESDEN

A progress report on the Dresden Boiling Water Power Plant (180,000 kWe) was presented to the 22nd Annual Meeting of the American Power Conference on 31 March, 1960, by J. J. Poer, Commonwealth Edison Co. and V. D. Dixon, General Electric Company.

While more fuel was being loaded after criticality, the progress report states, it was found that there was no effect on the reactivity of the reactor when three of the control rod drives were operated. Critical loading and testing were stopped and investigation showed that the poison blade had become disconnected from the drive mechanism because of shearing of the shear pins. Loss of buffering action at the end of the scram strokes because of damaged seal rings and too rapid deceleration of the rod as it entered the buffering region are said to be the two main causes of the shearing. The damaged seals were replaced, modifications made to the hydraulic system, and clearances of connecting linkages modified. After testing of the drive mechanism no further trouble has been noted.

Tests with 320 elements were completed in March and continued step-by-step loading will be carried out to the point where power testing should begin.

*DRESDEN POWER-TEST PROGRAMME*

| TEST | PURPOSE |
|---|---|
| *Prepare for startup* | Complete preoperational, initial-loading and low-level test programmes |
| *Recirculation pump* | Determine core flow and system pressure-drop characteristics |
| *Shutdown and safety* | Test safety system and capability of plant for safe operation |
| *Reach critical and initial nuclear heating* | Start reactor and bring to temperature while providing conditions for other tests |
| *Temperature coefficient of reactivity* | Find $\triangle k/k$ per °F and critical rod patterns vs. temperature |
| *Rod pattern* | Find near-optimum rod configuration for flux shaping |
| *Stability* | Predict stability at next power step and as function of void fraction |
| *Turbine* | Bring turbine to speed and set controls |
| *System* | Determine response and stability of pressure regulator, turbine governor, and reactor (these constitute the control loop) |
| *Single- and dual-cycle* | Determine plant stability at greater than rated voids in the core. Determine response and manoeuvrability of the dual cycle |
| *Plant performance* | Part-to-full-load performance, Btu/kWh and equipment - performance specification |
| *System expansion and vibration* | Determine adequacy of expansion and vibration provisions |
| *Xenon peak* | Obtain peak Xe value and high Xe concentration startup information |
| *Radiation monitoring* | Determine adequacy of shielding and verify shielding calculations |
| *Water treatment* | Maintain specified water quality and conditions |

## TURBINES FOR REACTORS

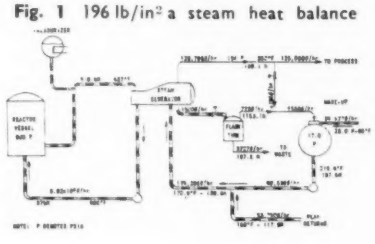
A single-stage liquid-cooled turbine which has been operated at Pametrada at 2200°F (1200°C) was described in a paper read to the Royal Institution of Naval Architects by Pametrada's director, Dr T. W. F. Brown, C.B.E., D.Sc., S.M.

The paper, 'A marine engineering review—past, present, and future', says a great deal of experimental work is still required in relation to mechanical details, ability to burn residual fuels and layout of the component parts, particularly combustion chambers. However, it holds great promise in the future as already it has been shown that the mean metal temperature in the rotor blading is 700–800°F, the maximum local temperatures being 1000°F when operating in a gas stream at a temperature of 2200°F. The blade metal temperatures are actually lower than those in an uncooled gas turbine with an inlet temperature of 1250°F. The temperature at the rotor where the blades are supported is that of the cooling water, i.e. not exceeding 140°F (60°C). Full strength can consequently be developed by the alloys used in blading, rotor, and other parts and no question of creep or life is involved at the parts of greatest stress.

This turbine will be of especial use in high-temperature gas-cooled reactors either in a straight cycle or with a free-running gas-turbine circulator.

Coolant fluids which could be used include helium, nitrogen, and carbon dioxide. There is general agreement about optimum cycle conditions for these coolant fluids (which will be working fluids in the turbine if no heat exchanger is used) and that differences between the peak efficiencies are small. Since comparisons should be based on constant maximum cycle pressure, a fluid having a small optimum pressure ratio such as helium has an initial advantage in that the L.P. section of the circuit can be at a higher pressure. The relatively good heat transfer properties of helium reduce the size of the heat transfer equipment relative to nitrogen and carbon dioxide.

**Fig. 1** 196 lb/in² a steam heat balance



## NUCLEAR PROCESS HEAT

Following the issue of report ANL-6009, the AEC requested more information on the chosen reactor concept, PWR, to investigate the potential of aluminium-clad fuel elements for the production of low pressure 30 lb/in² a saturated steam.

Consequently a modified design was presented in an addendum to ANL-6009 and described fully by R. R. Rohde of the Argonne National Laboratory at the 1959 Symposium on Low-temperature Nuclear Process Heat held at the AEC Headquarters building, Germantown, Maryland, October 1, 1959 (TID-7580).

The diameter of the containment vessel has been reduced by more compact arrangement of the equipment and the steam generator moved below the floor to make the shield problem less acute. In the pressure vessel, water at 400°F enters at the centre, passes through the core, turns and goes downwards and leaves the pressure vessel at the side nozzle. One hundred fuel elements are fastened to the tube sheet type of end fitting to make a subassembly. Fuel is pelletized $UO_2$ with a radial gap of 2 mils for helium. Aluminium clad thickness is 0·040, Zircaloy 0·017. Figure 1 gives the 196 lb/in² a steam case, the primary flow rate is 3,920,000 lb/h of water at 400°F heated to 432°F. In the steam generator it drops to 400°F. Figure 2 gives the 30 lb/in² a case, the primary flow is the same. Power output is 30·6 MW.

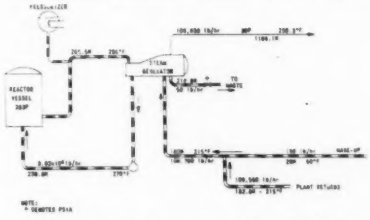


**Fig. 2** 30 lb/in² a steam heat balance

## *New Reports*

*Handbook of apparatus used in dosimetry, radiometry and electronics, counters, scintillation apparatus and photomultipliers.* Trans. from Russian. 190 pp. *Report JPRS-942-D.* Available only from OTS $2·75.

*Direct conversion applied to nuclear heat sources.* M. Barmat. Martin Co. June 1959. 58 pp. *Report AECU-4483.* Available from OTS at $9·30 or depository library (on Microcard).

*Proceedings of a Conference on the Theoretical aspects of controlled fusion research,* Gatlinburg, Tennesee, April 27–28, 1959. 232 pp. *Report TID-7582.* Available from OTS at $3 or depository library.

*The fast multiplication effect of beryllium oxide in reactors.* W. Häfele and M. Tsagaris. Oak Ridge National Laboratory. Dec. 1959. 17 pp. *Report ORNL-2849.* Available from OTS at $1 or depository library.

# BUSINESS NEWS

**GEC FURNACES FOR RISLEY** The General Electric Company Limited has received a further contract from the United Kingdom Atomic Energy Authority, Risley, for electric furnaces for use in the production of plutonium metal. This latest order covers reduction and fluorination furnaces. The GEC in the past have supplied a total of two reduction and eight fluorination furnaces to the AEA, Risley.

The fluorination furnace is rated at 10 kW and is of the horizontal front-loading type, complete with muffles. The inner surface of the muffles and doors are lined with platinum. A forced cooling system is incorporated to enable the charge to be cooled within a stipulated time.

The furnace for the reduction process is rated at 50 kW. It is of a bell-type design and has a forced cooling system similar to the fluorination furnace.

Electrical equipment being supplied includes regulating transformers, temperature control gear, and the necessary switchgear.

**KANIGEN PLATING AGREEMENT** The increasing use of Kanigen — the new chemical nickel phosphorus plating process operated in the UK by Albright & Wilson (Mfg.) Ltd.—is reflected in a recent agreement between General American Transportation Corporation of Chicago, from whom A & W derive their British Commonwealth licences, and the Union Carbide Nuclear Company. Union Carbide Nuclear will in future be licensed to operate the Kanigen process at these two plants.

Some months ago Albright & Wilson (Mfg.) made extensive alterations to their Oldbury, Birmingham, plating plant to cope with a greater and more varied range of companies. It is anticipated that the growing demand will force further extensions to existing capacity in the near future.

**USSR ORDERS FERRANTI EQUIPMENT** An order worth over £300,000 for high voltage testing equipment has been placed with Ferranti Ltd. by the USSR. The contract was negotiated through v/o Machino-import of Moscow and is the largest order for equipment of this type ever placed with a British manufacturer.

**ORDER FOR ELLIOTT NUCLEONICS** Atomic Power Constructions Limited have given a letter of intent to Elliott Nucleonics Limited for the contract for reactor flux scanning equipment for the Trawsfynydd nuclear power station. The equipment, 50 units plus spares, will be used to measure the neutron flux distribution. Delivery is scheduled for 1962–63.

The system to be used at Trawsfynydd follows the method used at Calder Hall, with some modifications. For technical details see *Progress in Industry* this issue.

**JOHN BROWN AND SOLARTRON** The formation of a jointly-owned new company, Solartron–John Brown Automation Limited, is announced by John Brown and Co. Ltd. and the Solartron Electronic Group Ltd. Its headquarters will be at CJB House, Eastbourne Terrace, London, W2. Main activity will be the design and manufacture of automation systems.

Mr. C. G. F. Aldridge, chairman, Association of Supervising Electrical Engineers, speaking at the opening of the ninth Electrical Engineers Exhibition, Earls Court. Over 460 exhibitors were represented at the show

**MULLARD ACCELERATOR FOR AEA** A development contract for a mobile linear accelerator designed to take X-ray photographs of the welds in the pressure vessel of a nuclear power station has been placed by the UK Atomic Energy Authority with Mullard Equipment Ltd. The machine is expected to be operational towards the end of the year. The contract results from investigations, commissioned by the Authority.

## OVERSEAS

**MORE BRITISH FIRMS AT HANOVER** A record number of British firms are exhibiting at the Hanover Trade Fair which ends on May 3 after ten days showing. Over 90 individual firms will have their products on view. One of the most interesting exhibits is EMI Electronics Limited's new portable contamination monitor. This carries its own battery supply and uses dual phosphor techniques for simultaneous monitoring of alpha and beta contamination on laboratory benches and other surfaces. EMI are members of Electronic Components Centre (GB) Ltd.

**NUCLEAR FUELS WAREHOUSE** Mallinckrodt Nuclear Corporation is building a new atomic fuels warehouse and an extension to its nuclear fuels research department at its Hematite, Missouri, plant. This will be the third expansion since the plant was built in 1956 and will replace space taken by growing research and development activities.

The new warehouse will use only 15% of its 80,000 cubic feet for actual uranium fuel storage. The remaining space is aisle and 'air' space. However it has been specially designed to permit multiple layer storage of uranium-filled shipping-containers and utilize maximum possible space.

## NEWSBRIEFS

**New Company.** British Insulated Callender's Cables Ltd., have formed a new company, Telcon Metals Limited. The new company assumed responsibility for all activities of the Metals Division of the Telegraph Construction and Maintenance Company Ltd. from April.

**AMF earnings.** Earnings and revenues for 1959 by American Machine & Foundry Company were the highest in company history and are expected to be even higher in 1960. Net earnings were 67% and gross revenue 23% over 1958 figures.

**AEC Patents.** The US Atomic Energy Commission has published a four page pamphlet 'USAEC Patents Available for Licensing' (TID-4557-1st Rev) which, among other items, describes procedures for applying for patent licences. The AEC has also made available for public use 80 more patents owned by the Government, bringing to 2180 the number released for licensing by the Commission.

**New Italian firm.** Italatom of Milan has been formed by Montecatini, the Anglo-American Corporation of South Africa, Engelhard Industries and Mallinckrodt Chemical Works to manufacture natural, depleted and enriched uranium and thorium compounds as well as uranium metals.

**Montecatini.** Net profit in 1959 was 14·3% above that in 1958.

**Takeover.** Petrolite Corporation of Missouri has acquired all the assets of Internuclear Company, Clayton, Missouri, in exchange for stock. Petrolite manufactures chemicals and equipment for the petroleum and allied industries while Internuclear provides engineering and consultation services for the AEC and other nuclear organizations.

# New Product Survey

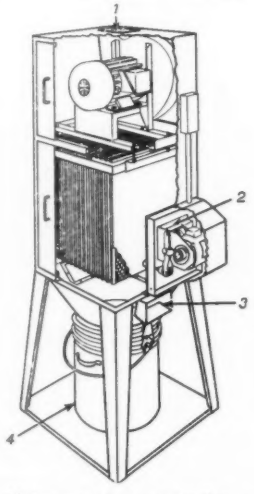
EQUIPMENT · INSTRUMENTS · MATERIALS

## DUST CONTROL

### flexible filter system

Dallow Lambert's Unimaster collects almost every type of dust produced by a wide range of machines, thereby enabling processes to be effectively controlled. This flexibility is made possible by a variation of fans and motors, filters and dust containers. Unimaster collectors can be used as small multiple connexion plants with runs of ducting attached.

The filter element consists of individual pads or envelopes mounted in a common frame sealed from the fan chamber. These pads are available in a variety of materials according to the dust being handled. The filter cleaning mechanism consists of an $\frac{1}{8}$ h.p. electric motor which transmits, by means of an eccentric, an oscillating movement to the inserts within the filter pads or envelopes. These inserts consist of a flexible rust-proof mesh mounted within a rigid frame. The oscillating movement causes the mesh within the frame to move rapidly backwards and forwards and induces an air current in a reverse direction through the filter fabric. This air current, allied with the oscillatory movement of the filter pads or envelopes, removes the accumulated dust on the filter fabric.




The Unimaster dust controller. 1—cleaned air outlet 2—filter cleaning mechanism 3—dust inlet 4—dust container

Tick **No 208** on reply card

## HYDRAULIC DAMPERS

### easing reactors' supports

A range of hydraulic units have been introduced by Electro-Hydraulics which have been designed for the protection of structures and relative components from the damaging effects of violent shock or vibration. These are particularly applicable for damping severe shocks such as arise from earthquakes on the gas ducting of power stations or on the containment vessels in nuclear propelled ships during bad weather.

The unit consists of a cylinder, mounted in a vertical position, the closed end of which is formed with an integral forked lug for attachment purposes, and five bosses forming fluid connexions. Moving axially within the cylinder is a piston secured to a piston rod which passes through a diaphragm dividing the cylinder to form a reservoir and damper chamber. When the piston moves down the cylinder the fluid displaced passes through fluid connexions, the restrictor, and subsequently into the reservoir. The fluid from the reservoir will at the same time be drawn unrestricted through the inlet connexions into the damper. Movement of the piston in the opposite direction reverses this flow sequence. While limiting the travel of the piston in the event of sudden movement, the one-way restrictors incorporated in the unit, offer negligible resistance during a slower movement.

When mounted in an inaccessible position the unit can be recharged remotely. Longitudinal drillings in the piston rod permit the passage of fluid through non-return valves to both the upper and lower face of the piston during recharging. Fluid is discharged via the reservoir and out at a fluid level connexion. A feature of the design is that recharging does not interfere with operation and that if the unit does operate while recharging is in progress, high pressure from the damper is prevented from reaching the filling lines by non-return valves.

Tick **No 209** on reply card

## COOLING TOWERS

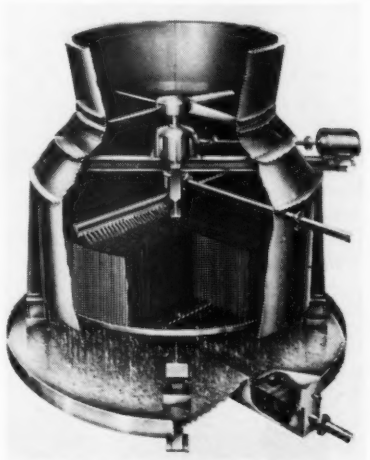
### new fill reduces size

A completely new type of tower by Thermotank, weighing less than half as much as conventional towers of similar capacity, has several novel features in design and construction. The structure is fabricated from rolled steel sections, treated against corrosion, and the casing is of galvanized sheets, with side panels which can be removed for maintenance.

The tower contains a top-mounted fan which draws the surrounding air up through it from the bottom. The fill is arranged across the inside of the tower with the channels disposed vertically, and the cooling air passes up through these channels. Water enters the tower at the top, and is distributed across the surface of the fill by a centrally-mounted rotating header pipe containing a number of perforations along its length through which the water streams on to the fill. The perforations vary in size along the length of the header to ensure an even distribution of water.

The fill which is made from alternate flat and corrugated sheets of a plastics-impregnated cellulose material has a high wettability and it is made up into rigid units which require only a very light supporting structure at the base.

The water which passes down the walls of the channels in a thin, continuously-moving film ensures the maximum area of contact between the rising currents of air and the water, thus utilizing the volume of fill to its greatest capacity. A catchment tray at the base of the tower collects the cooled water for return to the appliance in which it is required.



The largest size Thermotank cooler is only 20 ft × 12 ft but takes 90,000 gallons of water an hour

Tick **No 210** on reply card

## CONCRETE AGGREGATE

### heat resistant

A new synthetic aggregate, Alag, for use with Ciment Fondu High Alumina Cement, results in concrete, with very good qualities of density, hardness and strength, in 24 hours.

Lafarge's Alag is dense, non-absorbent and extremely hard, with a hardness of 7·0 to 7·5 mohs (between quartz and topaz) which will cut glass. It is also heat resistant, the concrete being able to withstand temperatures up to 1200°C. After 24 hours the compressive strength of the Alag concrete is 13,000 lb/in² compared with 7500 lb/in² for normal Ciment Fondu concrete (after 7 days Ciment Fondu/Alag concrete has a compressive strength of 16,000 lb/in²). This

strength is approximately maintained through a heat range of 600° to 1200°C, figures for the higher temperature being 3800 lb/in² compared with 2800 lb/in² for ordinary refractory concrete.

The density of Ciment Fondu/Alag concrete is approximately 170 lb/ft³ air-dried.

At elevated temperatures the amount of water which combines with Ciment Fondu and Alag necessitates about 1½ to 2 times more water for the resultant mix than is used with ordinary Portland cement. This high content of combined water, together with high density, make it eminently suitable for concrete shields in atomic energy plants.

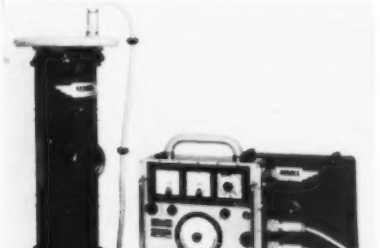
Tick **No 211** on reply card

## RADIOGRAPHIC INSPECTION

### portable unit for steel

The Andrex range of portable X-ray units distributed by Watsons consists of a 130 kV automatic unit, a 140 kV unit, a 160 kV unit, a 160 kV–360° unit, a 200 kV unit and a 260 kV unit, giving a range of penetration from thin aluminium to over 3 in. of steel. All of the units are of the robust, lightweight tank variety, with transformers in the X-ray head and no high tension cables.

The new 200 kV portable X-ray unit, weighing only 100 lb, provides a tube



The Andrex 200 kV portable X-ray unit penetrates steel up to 2¾ inches

current of 5 mA, and has provision for water cooling, giving a 100% duty cycle. It is suitable for 1½ in. steel, to Class 1 standards, or 2¾ in. steel using fast calcium tungstate intensifying screens.

Tick **No 212** on reply card

## THICKNESS GAUGE

### beta-mains unit

Baldwin Industrial Controls have recently introduced into their range of nucleonic thickness gauges a small portable mains operated unit designed to meet requirements of industry where the expense and refinements of the standard Beta gauge are not justified.

The gauge is calibrated in arbitrary units proportional to weight per unit area and the user can easily corelate a factor for his own particular product.

The Baldwin Beta gauge allows a variation of measuring head mountings and alternative radioactive sources

For simplicity, the gauge embodies only one radioactive source and detector. The output from the detector is compared with a calibrated reference potential and the difference in signal is amplified by an extremely stable low gain d.c. amplifier. The output signal is sufficiently powerful to operate both the built-in moving coil meter and, if required, an additional external milliamp recorder.

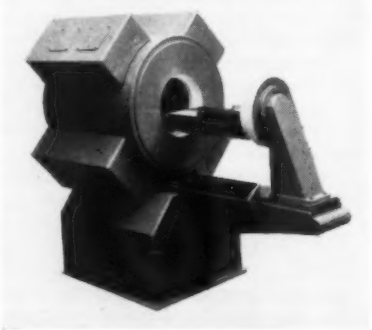
Tick **No 213** on reply card

## GAMMA DETECTOR

### low level counting

The NE 8105 counter from Nuclear Enterprises offers a method of measuring very weak radioactivity in large volume samples. A gamma ray detection sensitivity of 50 micromicrocuries per 60 lb sample in a 20 minute count can be achieved. The instrument operates as a gamma ray spectrometer with reasonable energy resolution and a two-channel analyser registers caesium-137 fall-out activity separately from potassium-40 activity, enabling foodstuffs, milk, water,

NE8105 low level counting facility consists of a twin-rack control unit and a large plastic scintillator detector unit (shown below)



etc., to be checked for contamination by fall-out. It also permits the use of much smaller quantities of radioactive tracers in chemical and other tracer applications. For tracer studies in biological experimentation, a simple and rapid measurement of total radioactivity of animals *in vivo* is possible.

The well in the Detector Unit is such that it will support samples on the motor-driven cradle up to 12⅜ in. dia. by 21¼ in. long. The sample is surrounded by a depth of at least 5 in. of NE 102 plastic scintillator and the scintillator by at least 3½ in. of aged lead (with very low RaD activity) to reduce background to a low level. The plastic scintillator is coated with a high performance diffuse reflector except where viewed by eight 5 in. diameter photomultipliers specially selected for high resolution.

The twin-rack cabinet contains one non-overloading linear pulse amplifier feeding into a two-channel discriminator plus scaler arrangement. Each channel consists of a single channel differential pulse height selector and a scaler with a pre-set count unit. In addition there is incorporated an e.h.t. supply unit, a voltage stabilizer and a photomultiplier voltage adjusting panel designed so that the gain of each photomultiplier can be individually adjusted to provide the same pulse height from each tube and thus give the optimum overall energy resolution from the eight tubes.

Tick **No 214** on reply card

## TEMPERATURE MEASUREMENT

### zero differential control

Ether's potentiometer recording controller has been designed for controlling and measuring temperatures of −200°C up to +2000°C. It is equally suitable for measuring variables, such as speed, strain, pressure and hydrogen-ion concentration, as well as any other quantity that can be expressed as an electrical signal.

A zero-differential control system operates through sliding-contacts on a variable-positioning pick-up track which is electrically connected in series with the control relay. The controller is provided with a 6-in. calibrated chart and ranges from 5 mV to 100 mV by using a plug-in printed-circuit unit. Calibration is accurate to 0·25% of span and sensitivity to 0·15%.

Tick **No 215** on reply card

## REMOTE CONTROL

### 18 ft stretch manipulator

Two new powered mechanical arms developed for remote handling of 'hot' materials have been introduced by General Mills. Model 550 has an arm stretch of approximately 18 feet outward from a shoulder boom which can hold

# EKCO Thermocouple Trip Amplifier

## SPECIFICATION

N642A

**Operational Trip Setting.** 0-600°C.

**Trip Margin Meter Indication.** 50°C. below trip.

**'Low-Margin' Trip.** May be set anywhere within the available trip margin range.

**Trip-Accuracy.** 0.4% of trip temperature.

**'Low-Margin' Trip Accuracy.** Better than 2% of the meter range. (Accuracy limited because the meter is used for setting).

**Hysteresis and Stability of Both Trips.** 2% of meter range.

**External Facilities.** The warning and trip relays each provide the following facilities which are connected to plugs at the rear of the instrument:—two sets of change-over contacts and two short circuit pairs.

**Input Signal Required.** 40 μV/°C.

**Thermocouple Earthing.** Can be at either terminal or at the hot point. (The amplifier is isolated from earth).

**Stability.** Cold junction compensation ensures that performance remains within the limits specified up to 40°C. ambient temperature. Performance is unaffected by mains variations of +8% —20%.

**Thermocouple Resistance.** Up to 250 ohms for performance specified. Up to 500 ohms for ambient temperature ('cold junction') up to 30°C.

**Response Time.** Less than 0.2 seconds.

**Recorder Output.** A 100 mV recorder can be driven to indicate the meter reading at an impedance of 100 ohms.

**Dimensions.** Front panel 4″ wide x 8¾″ high. Depth 13″.

**Mains Input.** 110-120v or 200-250v A.C., 45/60 c.s.

**Mains Consumption.** 20 watts approximately.

**See EKCO Electronics Stand at the I.E.A.**

**The Ekco range of reactor instruments also includes the following:—**

*Reactor Period Meters with alternative ranges.*
*Reactor Power Error Meter.*
*Resistance Thermometer Trip Unit.*
*Shut-Down Amplifier (with start-up facilities and shut-down state trip).*
*Fast Neutron Monitor (installed).*
*Misalignment Indicator (for coarse control arms.)*
*Leak Indicator (for external heavy water leak).*
*Effluent Monitor.*
*Battery Box Assemblies.*
*Logarithmic Gamma Health Monitor (installed).*
*Slow Neutron Survey Meter (portable).*
*Beta-gamma Survey Meters (portable).*
*Decade Voltage and Current Generator (general purpose test unit).*
*Reactor Period Meter Test Unit.*

## EKCO ELECTRONICS LIMITED

*Sales, Installation and Service*

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Tick **No 81** on reply card for further details

more than 100 pounds and it has eight separate motions. It can both flex and rotate at the shoulder, telescope its upper arm, bend its elbow, rotate at the elbow, bend its wrist, spin its wrist, and close its fingers with either a light touch or crushing force. All movements are controlled by a human operator at a small portable control box.

Model 150, smallest of the General Mills line of motor-driven, remotely-controlled manipulators, which was designed for alpha and gamma radiation work, can be mounted inside a small, airtight enclosure placed within a conventional 'hot cell'. It can also be mounted on an overhead bridge, a boom, vehicle, or a post, provides six separate motions and has a 360° shoulder swing.

Tick **No 216** on reply card

## X-RAY DIFFRACTION

### rapid crystal examination

A new multiplane X-ray diffractometer for fully automatic or manual operation developed by Seton Creaghe and based

In the new multiplane diffractometer the specimen holder can be rotated and reciprocated in the beam by two variable speed motors

on AEA design incorporates goniometric and scanning movements fulfilling the requirements of rapid operation and extreme accuracy. Its weight is approximately 75 lb.

The diffractometer is an X-ray instrument designed to use the Shulz method of determining the preferred orientation of crystals. This method enables the intensities of reflexions to be related, without correction, to the number of crystals reflecting. By this method the instrument can be used to examine the crystal structure of a specimen in any plane by the simple but precise adjustment of the goniometer ring which carries the specimen holder and a beam width limiting slit. It is possible to separate an $\alpha_1, \alpha_2$ doublet less than 6 ft apart.

The geiger counter arm and goniometer ring are carried by concentric bearings and the gearing between them gives a 2:1 angular movement. The goniometer ring can be adjusted separately in relation to the counter arm and then clamped. Slit systems are provided for the incident and reflected beam. These are accurately located and various angles of beam spread can be provided. Since the slit system is arranged in a simple geometric ratio careful choice of slits can double the range of receptor and divergence angles.

Tick **No 217** on reply card

## SCINTILLATION DETECTOR

### low background counter

A new well-type scintillation detector with an extremely low background is now available from Tracerlab. The new instrument, the SC-57A, employs a ½ in. dia. γ well crystal that accepts standard 5 ml. sample vials. The crystal is shielded in all directions ($4\pi$ steradians) with at least 3 in. of lead and has a background of approximately 100 counts/min. The SC-57A is useful in any application requiring the assay of isotopes in liquid solution. Its efficiency for I-131 is approximately 45%, thus permitting a sample containing $5 \times 10^{-4}$ microcuries to be counted (to 5% probable error) in less than 1½ min. The SC-57A is particularly useful in clinical applications where it can be employed in blood volume determinations, PBI conversion ratio analysis, red cell volume and survival determination using Cr-51 and pernicious anæmia diagnosis using Co-60 labelled vitamin B-12. The transistorized pulse amplifier is externally mounted, thus contributing to stability and low noise level by eliminating heat build up in the photomultiplier tube.

A high resolution photomultiplier tube (RCA 6655 A) and an amplifier bypass switch make the SC-57A a useful instrument for spectrometry analysis of liquid samples. An optional accessory is a thin-walled beta well crystal which has an efficiency of 100,000 counts per minute per microcurie of P-32.

Tick **No 218** on reply card

## IN BRIEF

• **Vibration detection.** A light weight direct-reading vibration meter has been produced by Research & Control. It has a transistorized amplifier and is fed from a built-in chargeable miniature battery.

Tick **No 219** on reply card

• **Simplified fixing.** *Briticent Plasticlips* for securing cables, conduit, tubes and hose in diameters from ¼ in. to 3⅝ in. are available for use on concrete, stone, brick or timber surfaces.

Tick **No 220** on reply card

• **Infinitely variable.** Carter Gears have extended their range of hydraulic units by the introduction of their AL50 40 h.p. unit.

Tick **No 221** on reply card

• **New radiochemicals.** Six radiochemical organic compounds are available from Tracerlab labelled with Carbon-14: Acetone 1, 3-$C^{14}$ for industrial organic research; Bromoacetic Acid 1 and 2-$C^{14}$, and Malonic Acid 1, 3-$C^{14}$ for the synthesis of amino acids; Propylene 1-$C^{14}$ for determining chemical reactions and metabolic fate of the new plastic polypropylene; and, Tristearin Carboxyl-$C^{14}$ for the study of the metabolism of fats.

Tick **No 222** on reply card

• **Hydraulic pressure switch.** KDG Instrument's Piston-type Switch is designed for hydraulic installations where high rates of operation and sudden applications of pressure are encountered. It comprises a stainless steel housing and piston fitted with 'O' ring seal operating against a spring. Two models are available 0–2000 and 0–5000 lb/in², others with pressure setting dials.

Tick **No 223** on reply card

• **Aluminized asbestos cloth.** Strong, durable and impermeable to moisture, Turners Aluminised Asbestos can be applied over primary pipe insulation, fabricated into mattresses and applied for heat protection to personnel.

Tick **No 224** on reply card

• **Transistorized recorder.** Compact, inexpensive, servo-operated recorder from Fielden records any current or voltage normally indicated on a meter and is suitable for recording the output of other electronic or electrical equipment such as pH meters, smoke density detector, $CO_2$ indicators, beta gauges, tachometers etc. The minimum full scale deflexion is 25μA or 30 mV. Chart 6¼ in. diameter.

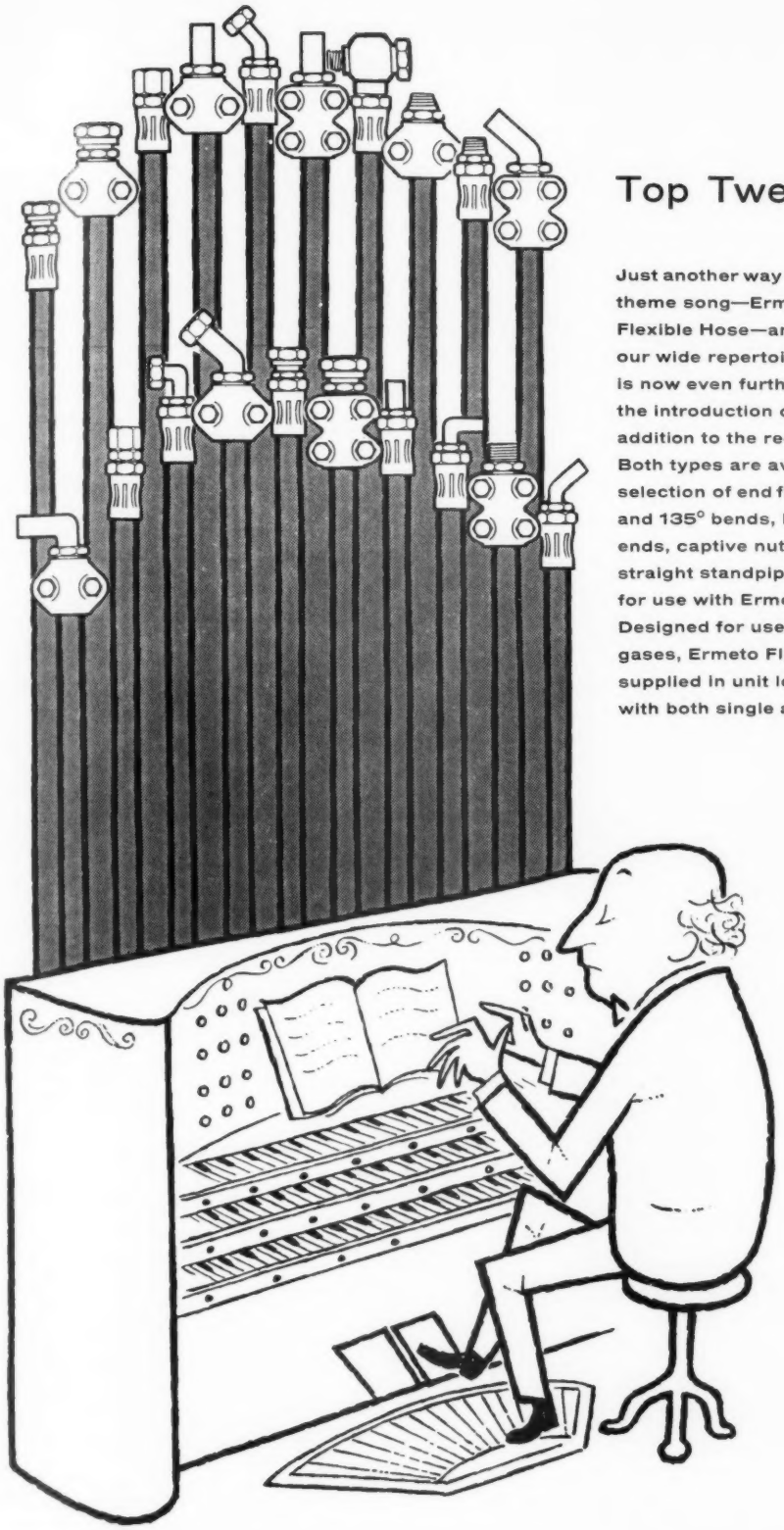
Tick **No 225** on reply card

• **Plastic scintillation fluors.** Semi-Elements, Inc., are producing the largest Plastic Scintillation Fluors ever made, weight approximately 400 lb before machining, 16 in. or more in diameter and 24 in. in length. They will be used for more efficient human body counts and for high energy radiation detection.

Tick **No 226** on reply card

• **Radiation shielding** Lead shielding chambers for handling radioactive materials are now available in a packaged form from Associated Lead. All have 2-in. thick lead walls, the same minimum internal dimensions, two sphere units for remote handling equipment and a standard lead window-frame for observation.

Tick **No 227** on reply card



## Top Twenty?

Just another way of presenting our favourite theme song—Ermeto High Pressure Flexible Hose—and reminding you that our wide repertoire of endings (all happy) is now even further augmented by the introduction of pre-swaged ends in addition to the re-usable twin saddle type. Both types are available with a wide selection of end fittings, including 90° and 135° bends, BSP male and female ends, captive nuts, in addition to the straight standpipe end which is suitable for use with Ermeto pipe fittings. Designed for use with most liquids and gases, Ermeto Flexible Hoses can be supplied in unit lengths of up to 60 feet, with both single and double wire braiding.

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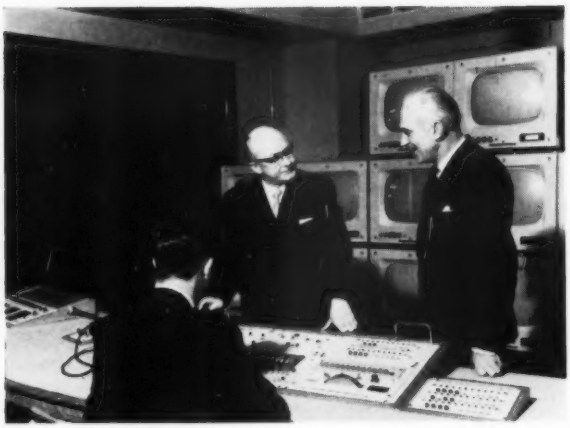


More EMI techniques may be exported to Canada according to Mr CLIFFORD METCALFE, Managing Director of EMI Electronics Ltd, seen here (centre) visiting an Associated Rediffusion studio. On his return recently from Canada he said 'I am very hopeful that we can help the electronic industry of Canada by transplanting some of the tremendous know-how at Hayes'

# *People*

*by John Radford*

I see that the board of management of the OEEC high temperature reactor project (Dragon) has approved the offer of the following appointments; Head of Administration, **R. K. Andresen** of Norway; Chief Engineer, **Gianfranco Franco** of Euratom; Deputy Chief Engineers, **S. B. Hosegood,** UK and **R. Tron** of Euratom. This round completes the allocation of top jobs on the project.

Rear-Admiral Andresen is Flag Officer West Norway and is a former naval attaché in London. Mr Hosegood has been associated with the Dragon project since 1959.

India's **Dr Homi Bhabha** is certainly getting around recently: last autumn he toured nuclear laboratories and power plant projects in the US; just lately he has been guiding the USAEC's Deputy Director of the Division of International Affairs, Myron B. Kratzer, and his team round India (*Worldview*, April); and the next move is to visit Russia in June at Mr Krushchev's invitation.

**Mr R. N. Millar** of the GEC has now returned from a short visit to India to investigate the prospects for British nuclear power plant exports (see *Worldview*, this issue).

**Mr Norman Readman,** Managing Director of The Consolidated Pneumatic Tool Co. Ltd. has been elected to the Board of Directors of the New York parent company, the Chicago Pneumatic Tool Company. I learn that Mr Readman is the first Englishman to go onto the parent company's board.

**Senator Spooner,** the Australian Minister for National Development, has appointed a personality well known to many of us here, **Dr George Clifford James Dalton,** B.E., B.Sc., D.Phil., M.I.M.E., as Director of the Lucas Heights Research Establishment of the Atomic Energy Commission.

Dr Dalton, formerly the Commission's Chief Engineer and Deputy Chief Scientist, was in charge of the Fast Reactor

Dr DALTON
moves up down under

Group of the UKAEA from 1947 to 1949.

S. Smith and Sons (England) Ltd. have announced that **Mr G. B. G. Potter** has been appointed to direct and coordinate Smiths Aviation Research and Engineering; this follows the reorganization of the aviation side of Smith's business.

After nine years as General Manager of the Wells factory of EMI Electronics Ltd., **Mr W. Pigdon** is leaving shortly to take up a new job as Executive Vice-President of EMI-Cossor Electronics Ltd., in Halifax, Nova Scotia, Canada.

**Professor Carlo Salvetti** has been named Director of the International Atomic Energy Agency's Research and Laboratories Division. He has been a consultant to the Agency for a few months and comes from the Italian Government's important nuclear centre Ispra on Lake Maggiore where he was Director General. **Sterling Cole,** Director General of IAEA, seemed particularly pleased in announcing this appointment; he emphasized the need to attract to the International Agency scientists of such high calibre as Professor Salvetti.

**Mr S. G. Spooner** has been appointed Works Manager of Marconi Instruments

Mr SPOONER
Promotion at Marconi

Dr THORP
Joins Semiconductors

Ltd., St. Albans, with responsibility for manufacturing activities, industrial relations, works services and welfare.

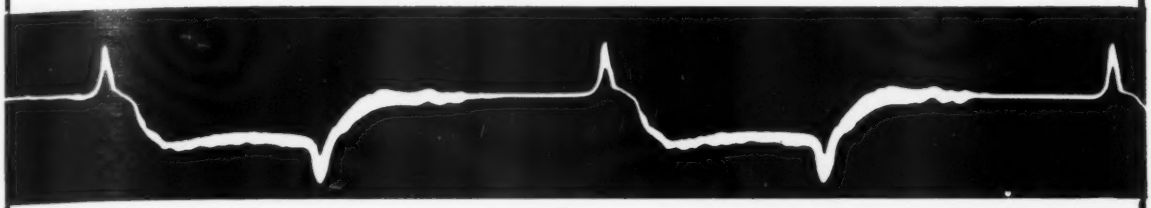
From Semiconductors Ltd. comes the news that following expansion the sales organization has been enlarged and **Mr J. H. Thorp** has been appointed Sales Manager. He moves from Texas Instruments Marketing Department.

Major changes in the organization of The Babcock and Wilcox Company's Atomic Energy division in Lynchburg, Va., have been announced by **Dr L. M. Currie,** vice-president in charge of the division.

Three new departments have been created. A Development department headed by **M. C. Edlund,** a Contract department under **R. P. Grimes,** and a Proposition department under the supervision of **D. A. Plunkett.** Dr Currie said that the changes were made 'after long and careful study, to consolidate our experience and align our capabilities with the type of nuclear business we expect in the future'.

The company's nuclear power projects include the NS *Savannah* and the Consolidated Edison Thorium Reactor.

# TRANSISTORISE *your switching circuitry!*



## 20 mμsec or 40 mμsec

**2G104 GERMANIUM** — **2S101 SILICON**

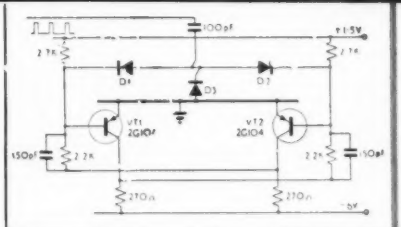
BVA SO-12 / JEDEC TO-18

| | $P_{tot}$ | | $f_1$ | | $V_{CB}$ |
|---|---|---|---|---|---|
| 150 mW | | 300 mW | | 300 mW | |
| 300 Mc/s | | 150 Mc/s | | 150 Mc/s | |
| 15 V | | 25 V | | 25 V | |

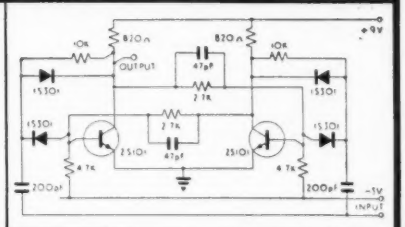
BVA SO-12 / JEDEC TO-18

*LOW SATURATION (BOTTOMING) VOLTAGE* — *OPERATION UP TO 150°C*

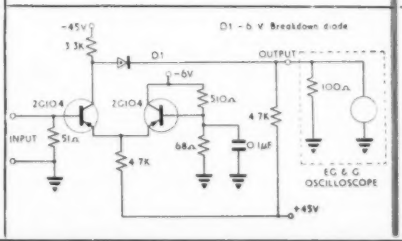
**10 Mc/s SATURATED SWITCHING**



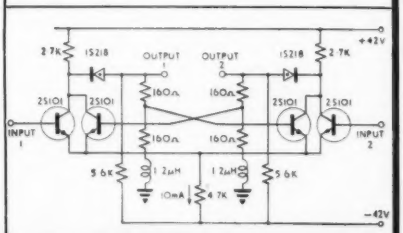
**5 Mc/s SATURATED SWITCHING**



**50 Mc/s NON-SATURATED SWITCHING**




**25 Mc/s NON-SATURATED SWITCHING**



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91/A5

# Diary

25–29 APRIL
International Compressed Air and Hydraulics Exhibition, Olympia, London

25–30 APRIL
Fourth Production Exhibition at the National Hall, Olympia, London, W14

25 APRIL—15 MAY
Royal Dutch/Shell Group 'World of Oil' exhibition at Herbert Art Gallery and Museum, Coventry

26 APRIL
*Some Recent Advances in Industrial Electrical Control Techniques* T. E. Barany Society of Instrument Technology 7.00 at Mansion House, 26 Portland Place, London, W1

26 APRIL
*Sealing against pressure and vacuum* Joint meeting of the Institution of Chemical Engineers and the Institute of Petroleum at Manchester

27 APRIL—6 MAY
Fuel Efficiency Exhibition, Grand Hall, Olympia, London

29 APRIL
*Some Aspects of Ionizing Radiation in Medicine* Dr. R. Morgan Institute of Physics 5.15 at University College of Wales, Aberystwyth

29–30 APRIL
Convention on Thermonuclear Processes. The Institution of Electrical Engineers at Savoy Place, London, WC2

2–4 MAY
*Non-destructive Testing* Joint meeting of the Société Française de Métallurgie and the Non-destructive Testing Group, the Institute of Physics at 47 Belgrave Sq., London, SW1

3–13 MAY
Mechanical Handling Convention and Exhibition at Earls Court, London, SW5

4 MAY
*High-speed Heavy-duty Diesel Engine* Dr. E. Schmidt 6.00 at The Institution of Mechanical Engineers, 1 Birdcage Walk, London, SW1

4–6 MAY
International symposium on distillation. Joint meeting of the Institution of Chemical Engineers and the Society of Chemical Industry, sponsored by the European Federation of Chemical Engineering, at The Dome, Brighton

5 MAY
*Direct Conversion—Its Physics and Applications* Donald H. Loughridge of GM Research Laboratories at Northwestern University, Evanston, Illinois, USA

11 MAY
Data Processing Section Annual General Meeting and *A Recording Stereocomparator* A. E. Adams, The Society of Instrument Technology 6.15 at Mansion House, 26 Portland Pl., London, W1

11 MAY
Sixth Standards Engineers' Conference British Standards Institution at Connaught Rooms, Great Queen Street, London, WC2

12 MAY
Industrial Television and its applications S. G. Gobbi 7.15 at Scottish Building Centre, Sauchiehall Street, Glasgow

16–25 MAY
Course on Reactor Environmental Health Problems, Robert A. Taft Sanitary Engineering Centre at Cincinnati, USA

18 MAY
Electronic Equipment Reliability Symposium at The Institution of Electrical Engineers, Savoy Place, WC2

18 MAY
*Factory Safety* Lecture 7.00 at Royal Society of Arts, John Adam Street, Adelphi, Strand, London, WC2

19 MAY
*Physical Problems and Prospects of Plasma Propulsion,* Frafft A. Ehricke of Convair Astronautics at Northwestern University, Evanston, Illinois, USA

23–28 MAY
International Instruments, Electronics and Automation Exhibition at Olympia, London, W14

24 MAY
Annual General Meeting, The Society of Instrument Technology 6.00 at Mansion House, 26 Portland Pl., London, W1

24–26 MAY
Electronic Forum for Industry Conference at Olympia, London Details from The Electronic Engineering Association, 17 Fleet Street, London, EC4

24–27 MAY
Exhibition of Drawing Office and Photocopying Equipment Lawes Rabjohns at Ealing, London

## *Further Ahead*

30 MAY—2 JUNE
First International Pipes & Pipelines Exhibition at Earls Court, London, SW5

7–13 JUNE
IAEA Radiation Dosimetry in Health Physics, Vienna

12–15 JUNE
Sixth Annual Meeting of the American Nuclear Society at Chicago, Illinois, USA

18–29 JUNE
Exhibition and demonstration of British Scientific Instruments at The Polytechnic Museum, Moscow. Details from SIMA, 20 Queen Anne Street, London, W1

20–26 JUNE
Fifth Nuclear Congress and seventh International Electronics and Nuclear Exhibition, EUR Congress Palace, Rome. Details from CNRN, Via Belisario, 1, Rome

23 JUNE
Symposium on Analytical Chemistry of Beryllium, UKAEA Industrial Group at Blackpool

27 JUNE—6 JULY
First International Congress on Automatic Control Moscow Details of papers from Institution of Electrical Engineers

28 JUNE—8 JULY
Royal Dutch/Shell Group 'World of Oil' exhibition at University College of N. Staffordshire, Keele

5–9 JULY
Fourth International Goitre Conference—Application of Radioisotopes at Thyroid Club, London Applications to S. Taylor, The Royal College of Surgeons, Lincoln's Inn Fields, London, WC2

21–27 JULY
Third International Conference and Exhibition on Medical Electronics. Held jointly by the International Federation for Medical Electronics and The Institution of Electrical Engineers at the Empire Hall, Olympia, London

21–30 JULY
International Nuclear Power Exhibition at Earls Court, London, SW5

26 JULY
Associated Electrical Industries Research Laboratories, Aldermaston, Royal Society visit leaves Burlington House at 9.00 Accommodation for 40 persons
Bradwell Nuclear Power Station Royal Society visit leaves Burlington House at 10.00 Accommodation for 40 persons

8–12 AUGUST
IAEA Effects of Ionizing Radiation on Seeds and its Significance on Crop Improvement. Probably at Karlsruhe

23–25 AUGUST
1960 Cryogenic Engineering Conference University of Colorado and National Bureau of Standards at Boulder, Colorado

25 AUGUST—3 SEPTEMBER
Tenth International Conference on High Energy Nuclear Physics International Union of Pure and Applied Physics and Commission on High Energy Physics at Rochester, New York, USA

6–17 SEPTEMBER
IAEA Use of Radioisotopes in Physical Sciences and Industry conference at Copenhagen

18–21 OCTOBER
First Effluent and Water Treatment Exhibition at Seymour Hall, London, W1

# INDUSTRIAL LITERATURE

**Non-destructive testing.** The latest issue of Solus Schall's 'News Letter' includes articles on ultrasonic radiation properties and testing and describes a portable Red Box radiation monitor.

Tick **No 252** on reply card

**Materials selection.** A useful metal selection chart from Meehanite, based on actual casting service records over 25 years, has been produced to help designers and users of castings to select the right type of metal for a particular job.

Tick **No 253** on reply card

**Metal filters.** Sintered Products leaflet on Porosint Rigimesh describes the uses being made of stainless steel for filtering, particularly, corrosive liquids.

Tick **No 254** on reply card

**Handling radioisotopes.** A guide to the safe use of isotopes has been published by the British Safety Council.

Tick **No 255** on reply card

**Scientific instruments.** Pye's latest catalogue describes several important new developments including apparatus for density measurement, process analysing and power stabilization.

Tick **No 256** on reply card

**Oil retaining bearings.** A leaflet from Bound Brook Bearings gives the properties and applications of their long-life porous bronze and iron bearings.

Tick **No 257** on reply card

**International isotopes guide.** Scientific Equipment Co. have issued the 4th edition of their 'Isotope Index' which is a complete purchasing guide to stable radioactive and labelled compounds and lists suppliers and manufacturers throughout the world.

Tick **No 258** on reply card

**Radiation equipment.** A wide range of Frieseke and Hoepfner instruments for measuring and detecting radiation is described in a recent catalogue from B & K Laboratories.

Tick **No 259** on reply card

**Valve data.** English Electric Valve's latest quick reference brochure gives abridged data covering their complete range.

Tick **No 260** on reply card

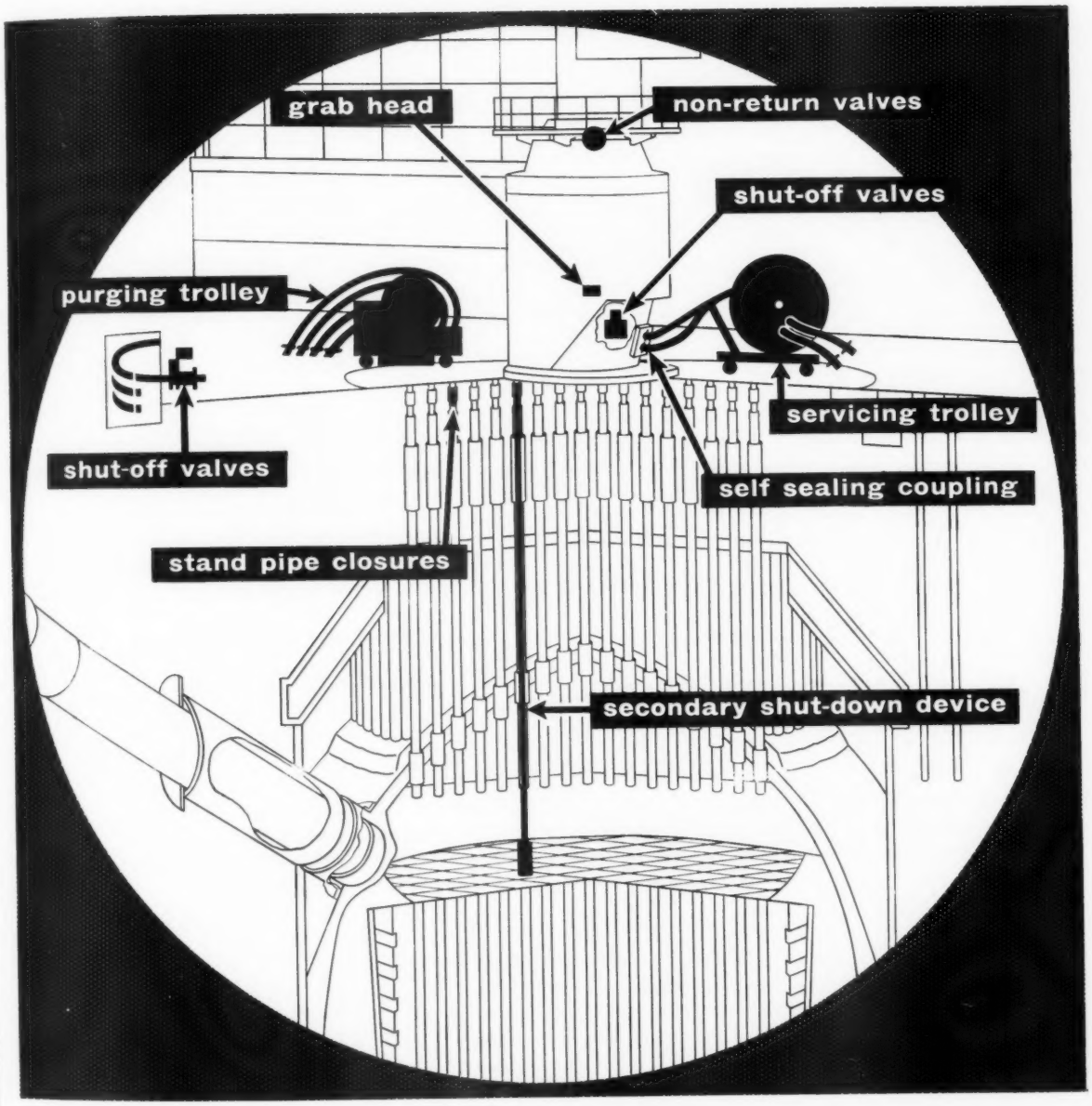
**Magnesium forgings.** Technical information on three Magnuminium alloys: 133, 133X and 266, together with a magnesium-zinc-zirconium alloy ZW3 is given in High Duty Alloy's latest pamphlet.

Tick **No 261** on reply card

**Special lubricants.** A leaflet from Rocol surveys the uses made of molybdenum disulphide as a lubricant and the various grades available.

Tick **No 262** on reply card

# FR services to the NUCLEAR INDUSTRY




## Flight Refuelling Ltd

Tarrant Rushton Airfield, Blandford, Dorset. Telephone: Blandford 501

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# Book Reviews

## Progress in automation

**Process Integration and Instrumentation** Published and Prepared by the Electrical Development Association 1959: 204 pp 141 figs. Price 8s 6d

This book is Volume 8 in the Electricity and Productivity Series and it discusses in an elementary manner the industrial progress in automation, particularly electrical techniques and components. It has been written for the industrial manager and the production executive of the medium and small concern and it should be especially valuable in helping to achieve the conceptional aim by indicating, as it does, the wide range of equipment and methods which can be applied. There are chapters which describe the links in automatic production sequences, namely sensing devices, instruments and instrumentation, electronic equipment, actuators and servomotors. There are also many examples of methods of automatic working, which should help the reader to appreciate the wide applications of the technique.

The authors have taken a great deal of trouble to write a book which will help the beginner to understand the problem and the way in which automatic techniques can help to solve them. It would have increased the value of the book, however, if some information could have been included of the actual economies made by the introduction of automatic methods of working.

**Denis Taylor**

## Properties of metals

**Progress in Metal Physics 8** edited by Bruce Chalmers and R. King London 1959: Pergamon Press Price 90s

This book is the eighth in a series which has established its value to the metal physicist and to those whose interests take them into this field. As in the earlier volumes, it consists of a number of unrelated articles each written by an expert, who is usually actively engaged in the subject on which he writes. In this volume there are five sections all dealing with some aspect of the crystal imperfections which play so large a part in determining the properties of metals. The subjects of the first four articles are 'Substructures in Crystals Grown from the Melt'—a discussion of the reasons why such crystals are not perfect; 'Grain Boundaries in Metals'—an attempt to bring up-to-date a subject already reviewed twice in this series; 'X-ray Studies of Deformed Metals'—an account of the effects which strains and crystal faults have upon detailed peak shapes; and 'Work Hardening in Metals'—a detailed description of the hardening which occurs when both face-centred cubic and close-packed hexagonal metals are deformed.

It is the last article, 'Defects in Pure Metals,' which will be of most value to those interested in the behaviour of metals in reactors. This is by Lomer of Harwell and deals principally with point defects (vacancies, interstitial atoms etc.) which are copiously produced whenever a fast moving neutron collides with an atom in a metal. These collision processes are evaluated, but most of the space is devoted to the properties of the point defects themselves and the effects that they have upon the properties of the metal. The subject is approached from a theoretical viewpoint but a short section at the end summarizes briefly some of the deductions from experiments.

This book is intended for the specialist wishing to keep informed about subjects bordering his own.

**R. S. Barnes**


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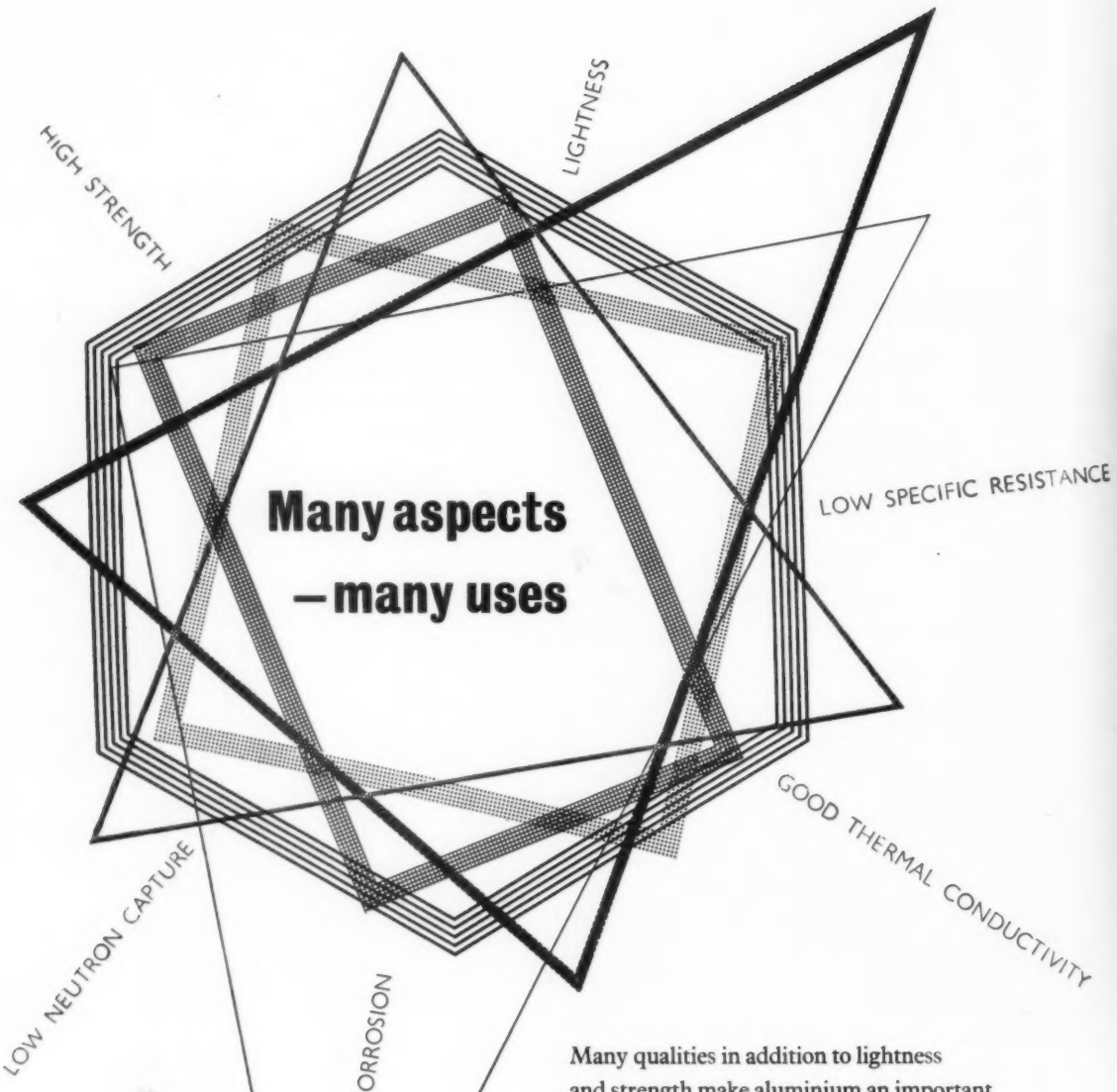


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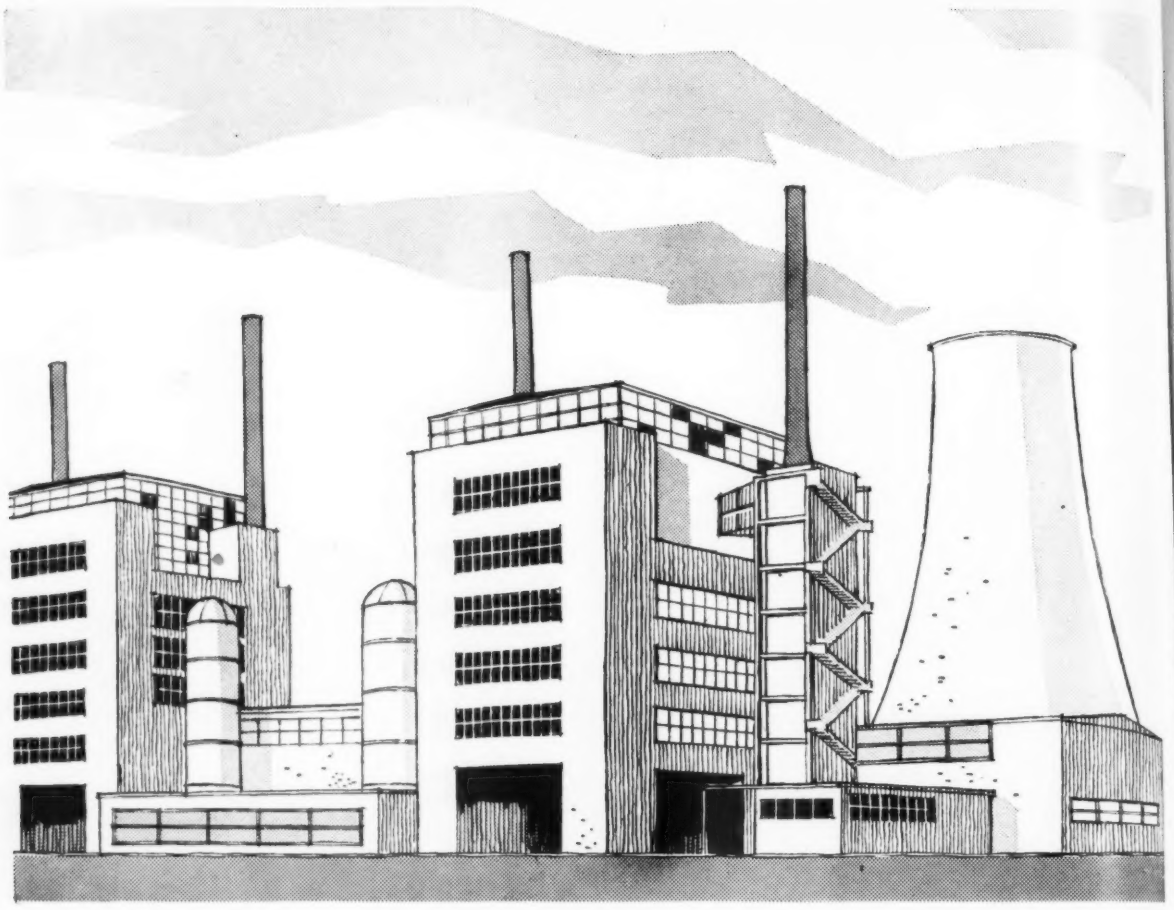

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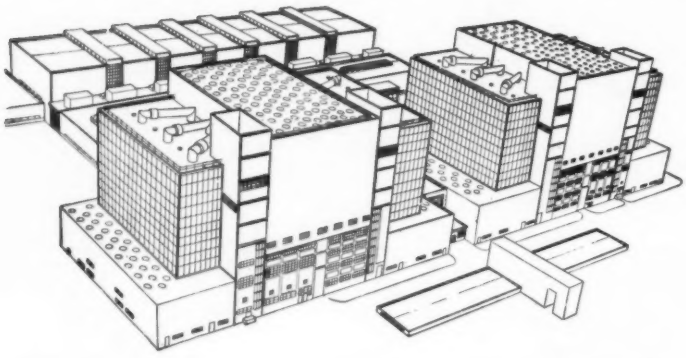

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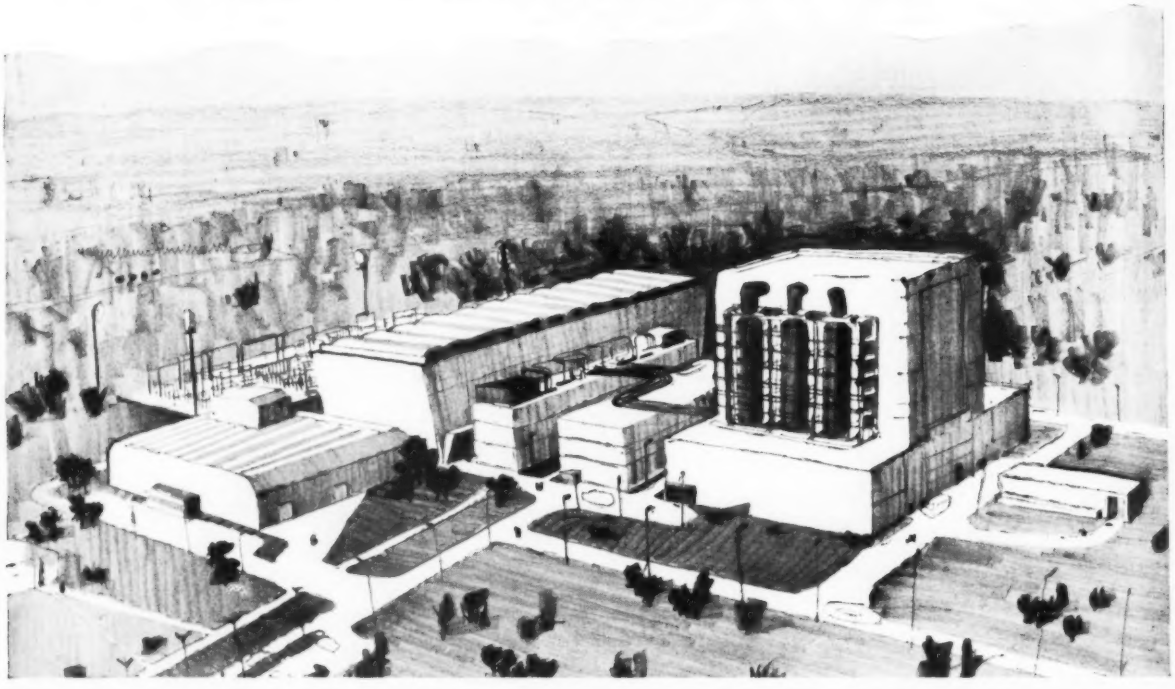

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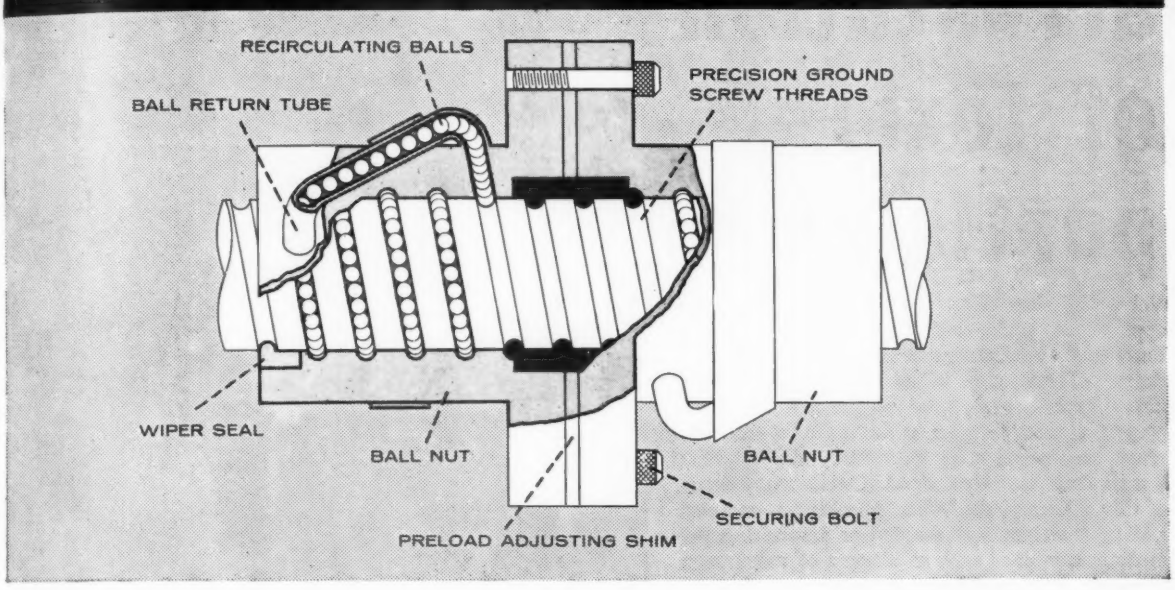


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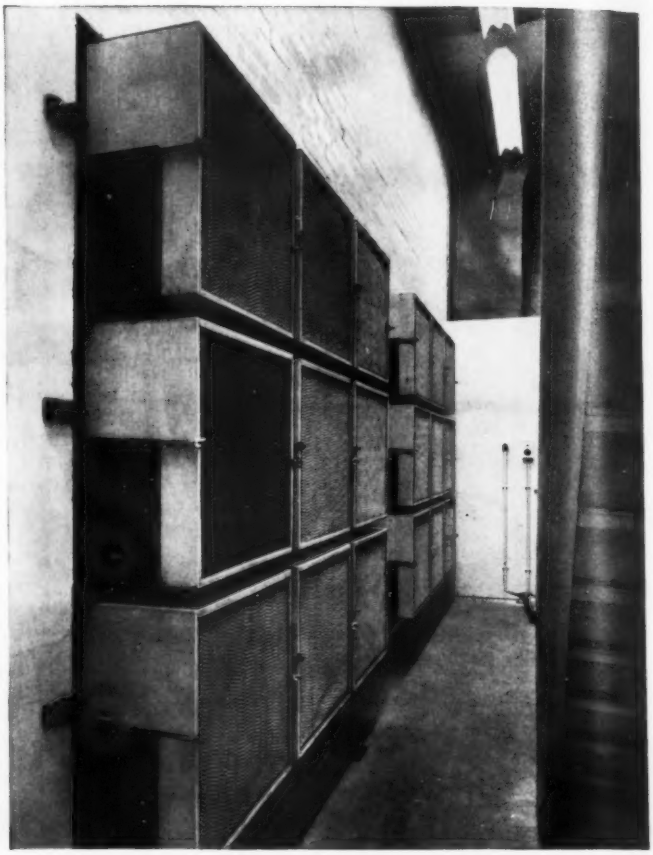

*A bank of Vokes 55 'Absolute' filters specified by the Ministry of Works for the ventilation plant (Extract) in the High Activity Materials Handling Building, Harwell. Vokes 44 'Absolute' panels are used on the intake.*

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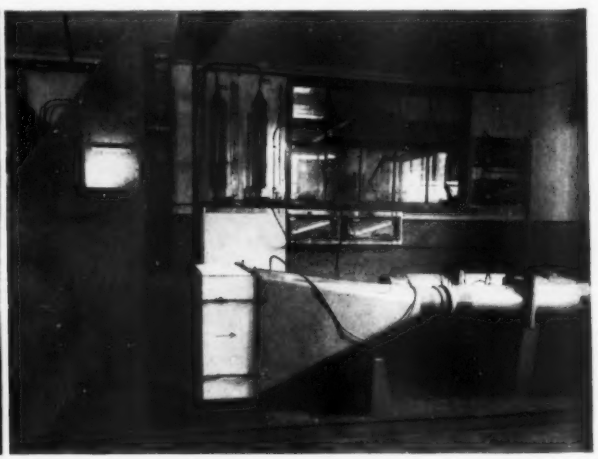

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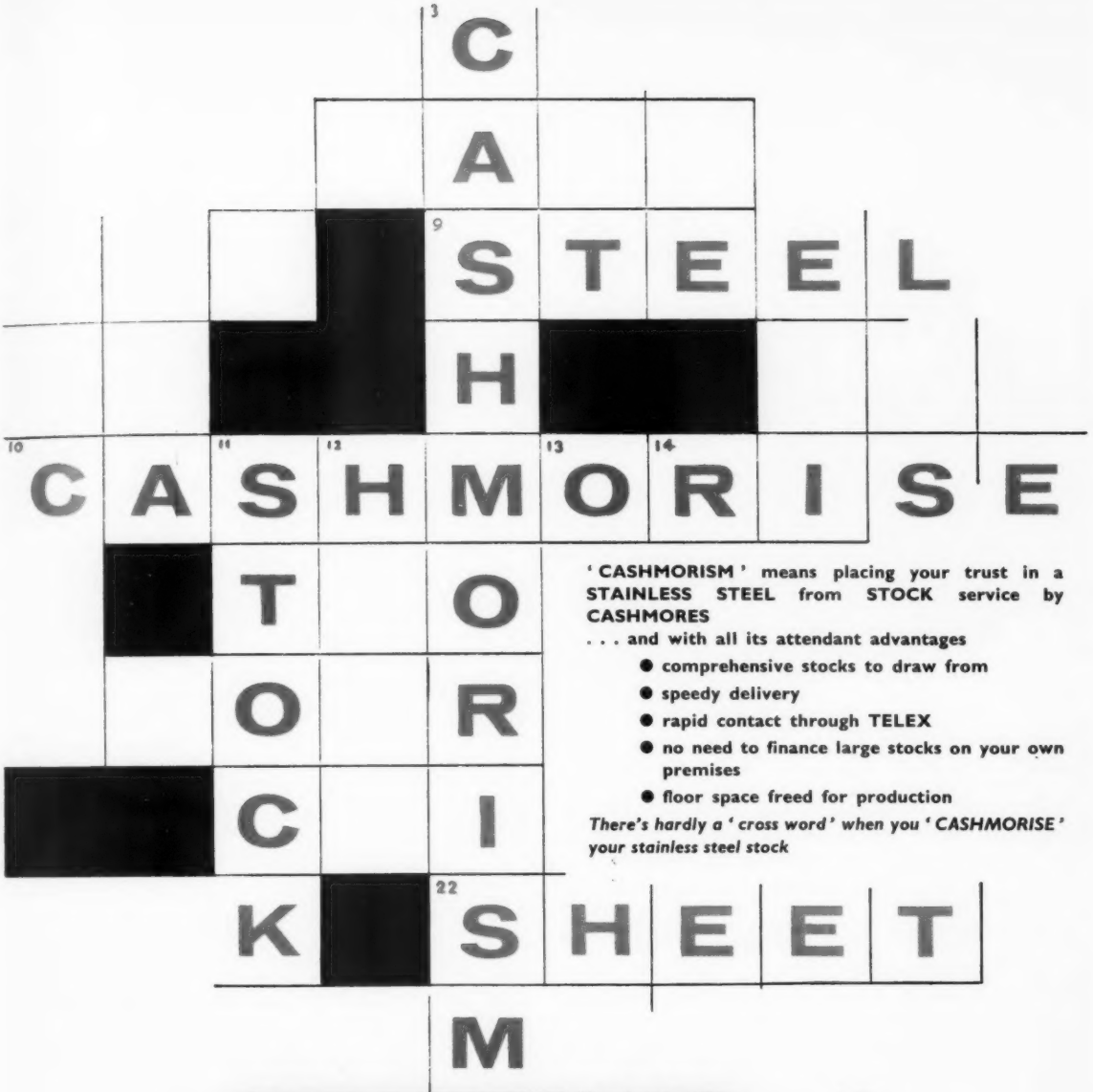


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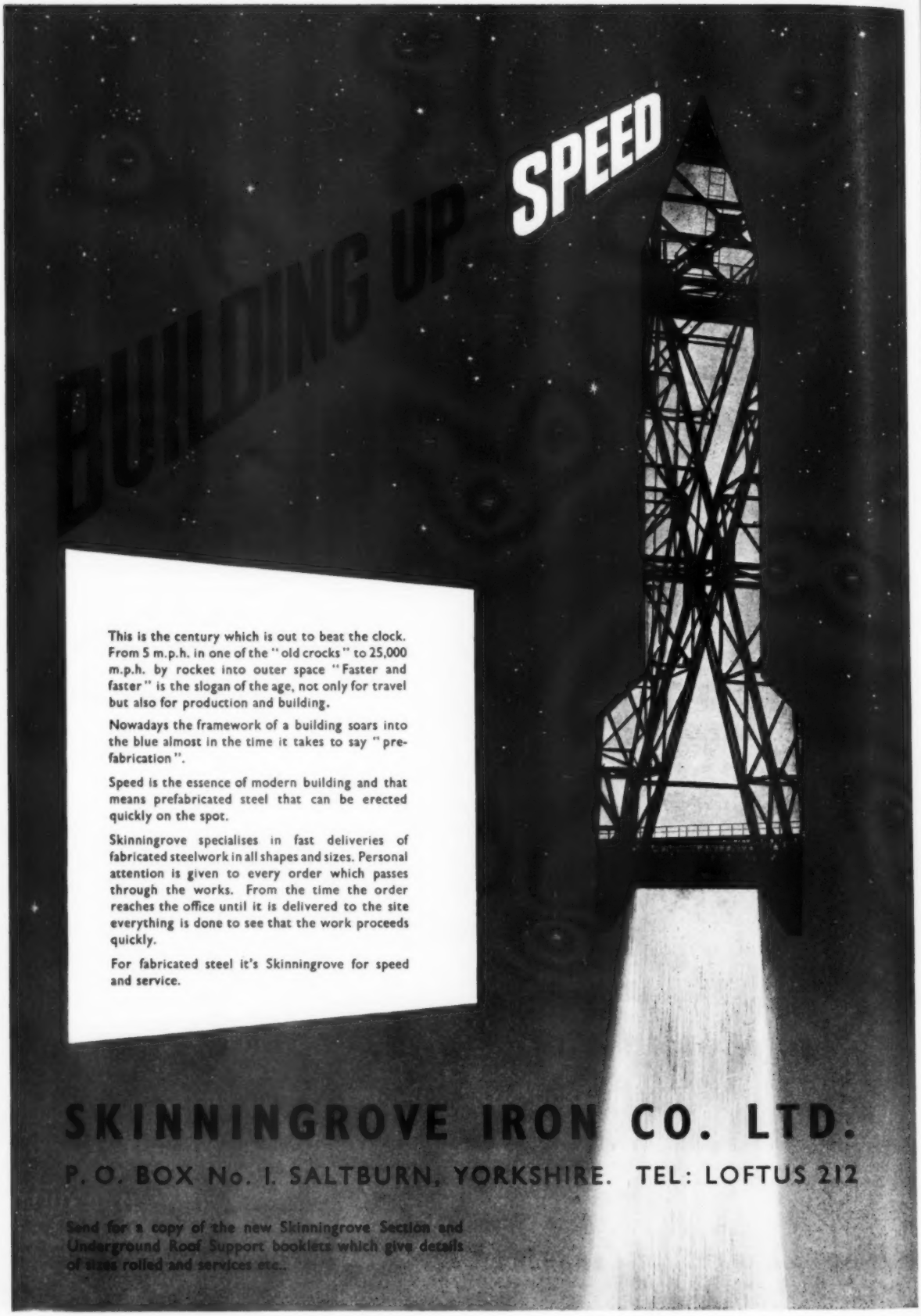
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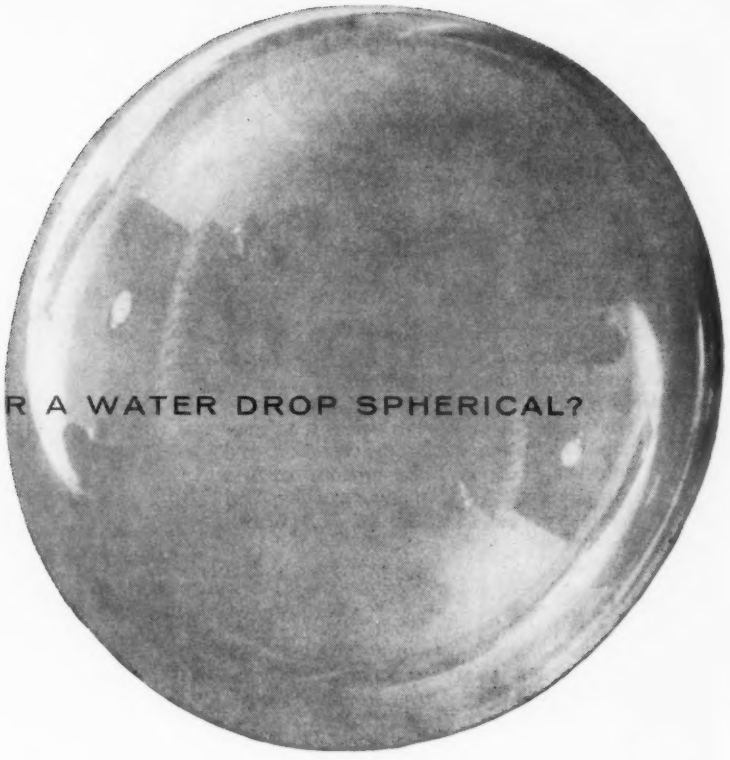

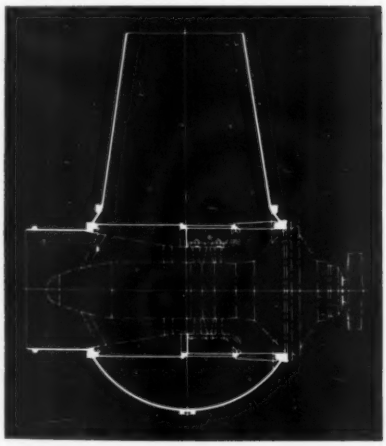

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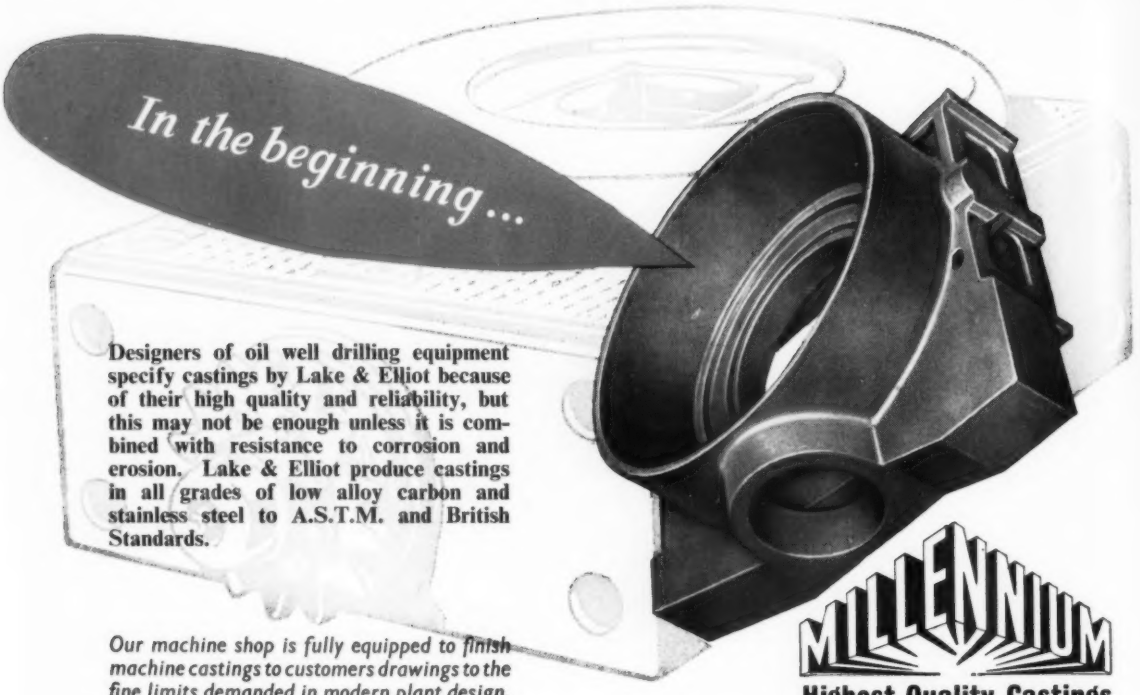

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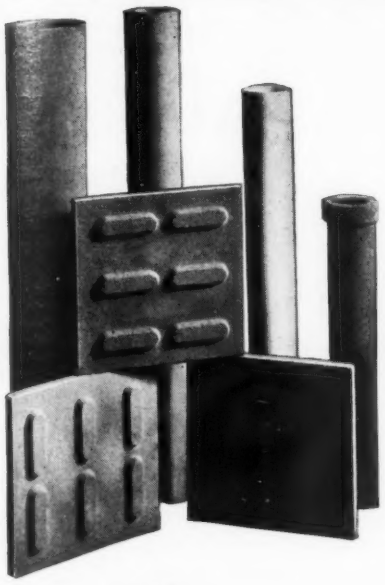

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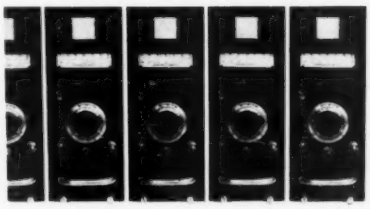

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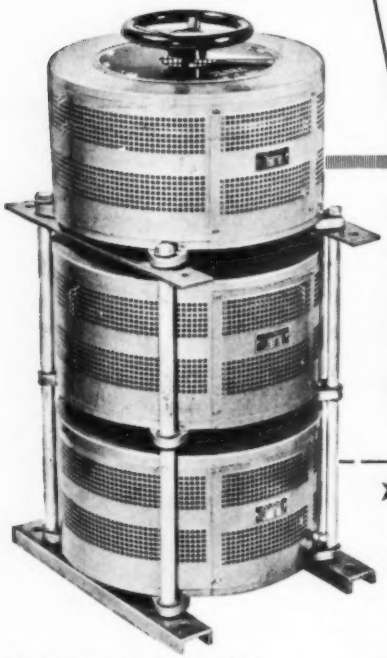

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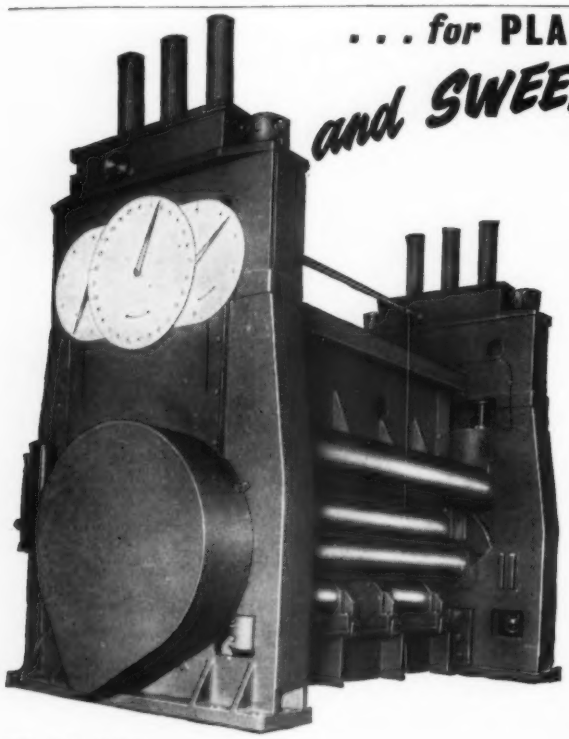

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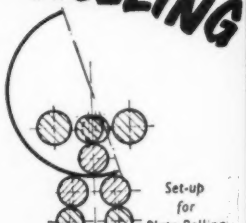
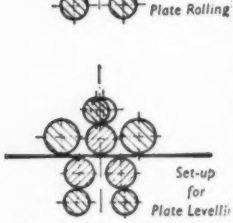


Set-up for Plate Rolling



Set-up for Plate Levelling

STAND 107, INTERNATIONAL MACHINE TOOL EXHIBITION OLYMPIA, LONDON 25 JUNE—8 JULY

This dual purpose Bronx Machine is specially designed for levelling plate up to 12ft. in width by 1½in. in thickness, down to ⅜in. in thickness. With the two outer rolls in the "up" position as shown in the illustration, the machine will also roll plate to a minimum radius of 2ft. The machine does not roll complete circles but will form sweeps, or radii, to a minimum half-circle of 4ft. diameter. Suitable, as it is, for both plate levelling and sweep rolling, it presents a most economical combination of machines.

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BRONX ENGINEERING CO. LTD., LYE, WORCESTERSHIRE

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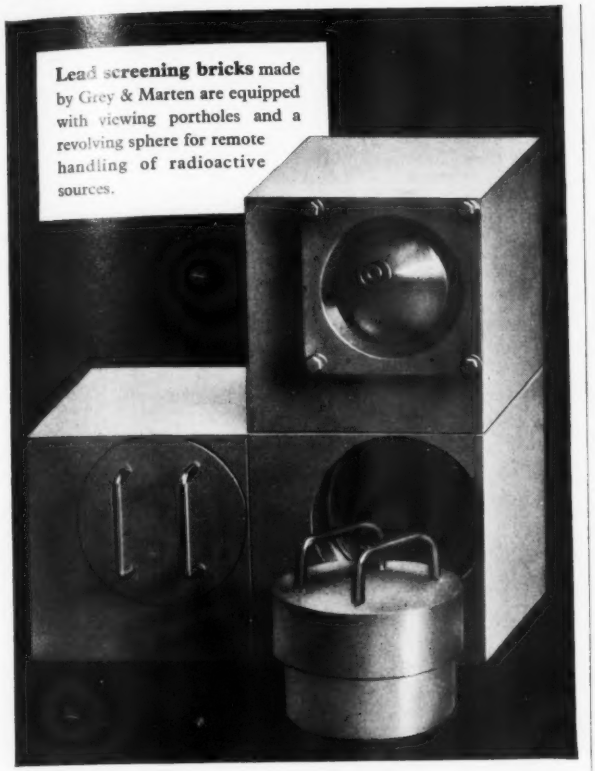
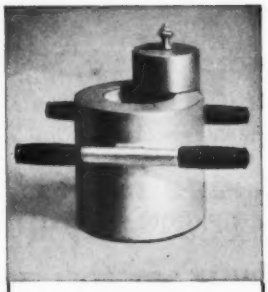


**Lead screening bricks** made by Grey & Marten are equipped with viewing portholes and a revolving sphere for remote handling of radioactive sources.

# Ask Grey & Marten about lead shielding

*(Their new subsidiary, James Girdler & Co., has all their skill and experience)*

GREY & MARTEN are experts in lead. They've specialised in the manufacture of *all* kinds of lead castings, fabrications and fillings for more than a century. Interlocking Lead Bricks (in one, two and four-inch thicknesses), Lead Sphere Units (in two and four-inch bricks), Aperture and Viewing Bricks, Lead Pots and Isotope Carriers are all produced under the Grey & Marten name. Now they have handed over this activity to their new subsidiary, James Girdler & Co. Ltd.



**Storage pot** typical of those used in standard safes not already fitted with lead protection, affords economical storage for radio-active material.

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*Established 1833*

CITY LEAD WORKS, SOUTHWARK BRIDGE, S.E.1
and at Birmingham, Manchester and Ipswich

## JAMES GIRDLER & CO. LTD

Mansell Works, Mansell Road, London W.3 CHISWICK 5991

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*(Sundays excepted)*

## 9.30 am - 6 pm

Make sure you visit the greatest engineering event of the year—The International Machine Tool Exhibition . . . No-one concerned with quantity production—whether in technical, administrative or operative capacity—can afford to miss this vast and truly comprehensive show at Olympia, London. It summarizes the best of contemporary production techniques; it shows the shape of things to come!

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Here's your opportunity to see them all under a single roof—to see many of them powered and in operation—to discuss their application to your own production problems with the world's best-informed production experts.

# International Machine Tool Exhibition 1960

Organized by The Machine Tool Trades Association, Brettenham House, Lancaster Place, London, W.C.2.

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# Safety in Comfort

At Siebe, Gorman & Co., comfort and efficiency go hand in hand: a fine example is the 'Vista' Mask.

The 'Vista' is a versatile mask that can be used with many types of equipment, from Compressed Air-line Apparatus to Gas Respirators. It is specially moulded for comfort and clear view—its plastic window is so shaped that vision remains undistorted at any angle. The air inlet is designed to prevent fogging, by deflecting inspired air over the inside of the window; and the mask itself can be tested for air-tightness before toxic atmosphere is entered. This is particularly important when it is used as a smoke mask—and the fitting we have designed for this purpose makes it impossible to wear the mask without both harness and lifeline, while the mask is still safe even if the bellows or blower are left unattended. Such thorough design is routine at Siebe, Gorman & Co.

The 'Vista' Mask is already in use with several Fire Brigades, and at the Atomic Energy Establishment, Harwell. It is approved by Ministry of Labour & National Service under Chemical Works Regulations, and the Ministry of Transport for use in ships. *Write to us for full details.*

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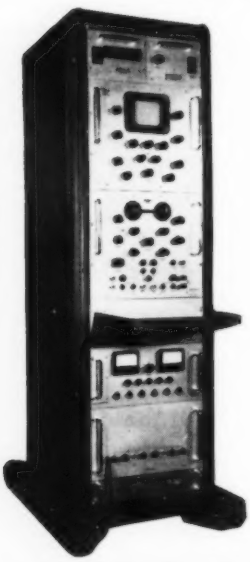

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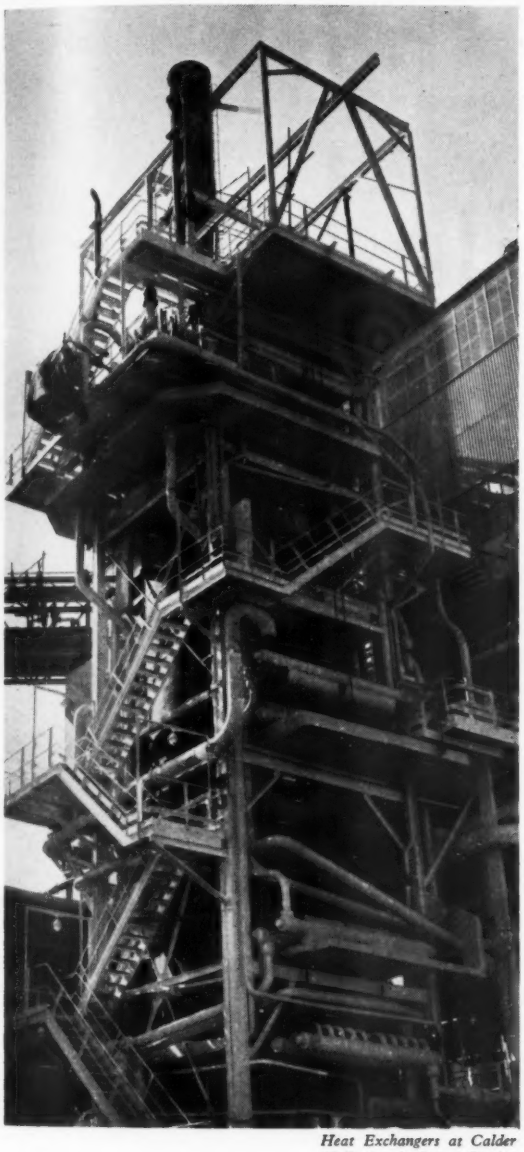

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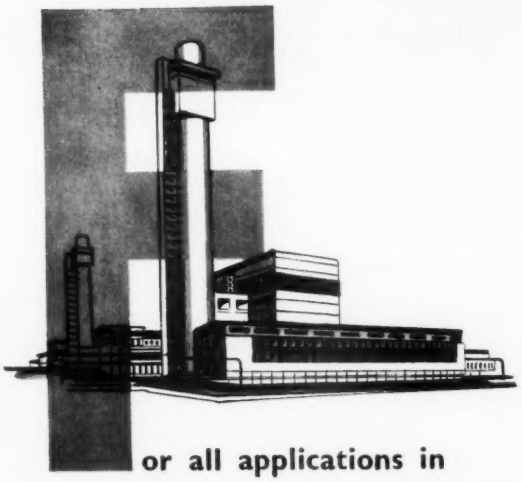

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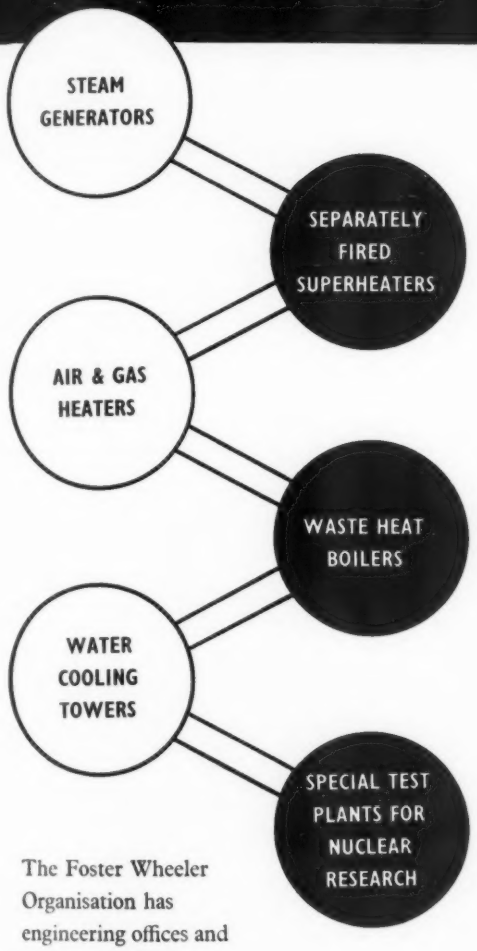


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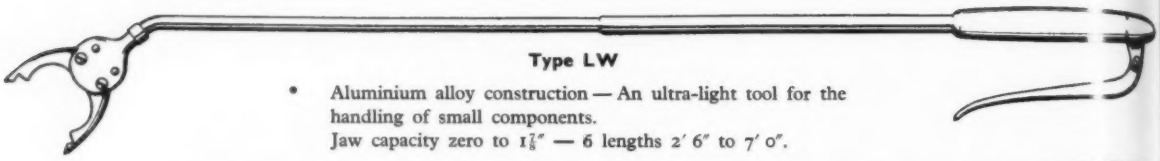
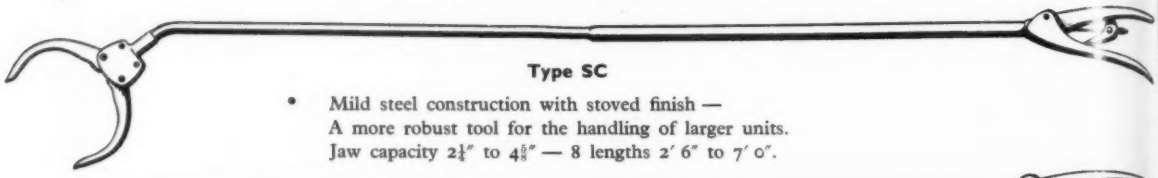


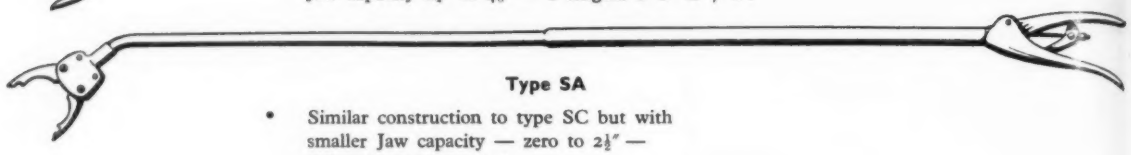
**Type LW**

- Aluminium alloy construction — An ultra-light tool for the handling of small components.
  Jaw capacity zero to $1\frac{7}{8}$″ — 6 lengths 2′ 6″ to 7′ 0″.



**Type SC**

- Mild steel construction with stoved finish —
  A more robust tool for the handling of larger units.
  Jaw capacity $2\frac{1}{4}$″ to $4\frac{5}{8}$″ — 8 lengths 2′ 6″ to 7′ 0″.



**Type SA**

- Similar construction to type SC but with smaller Jaw capacity — zero to $2\frac{1}{2}$″ —
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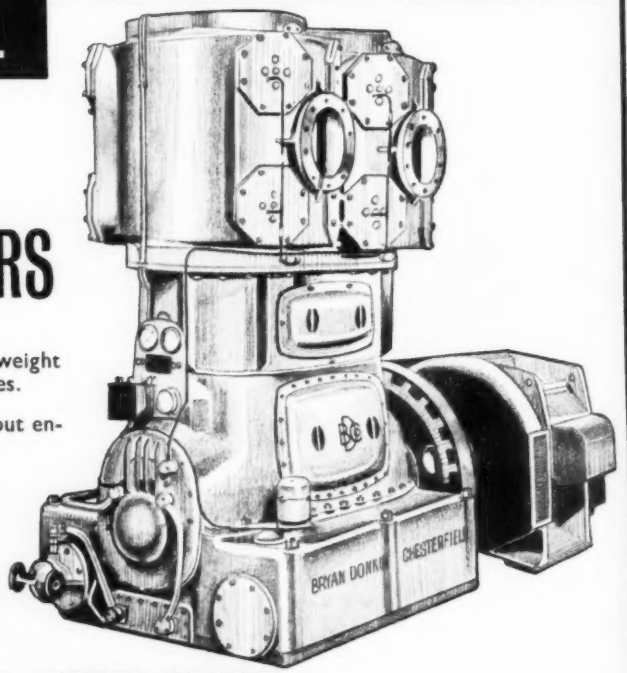


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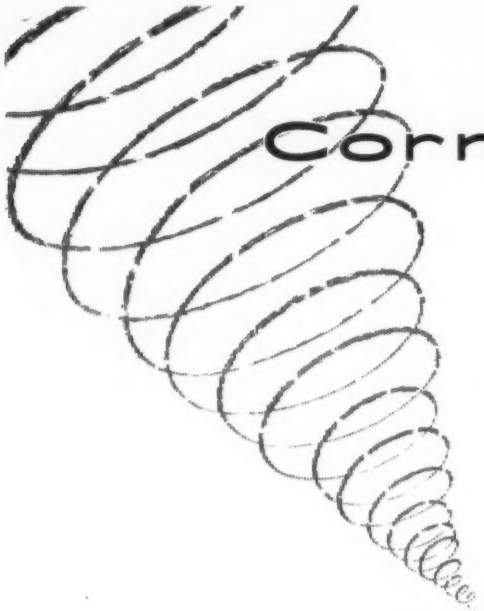

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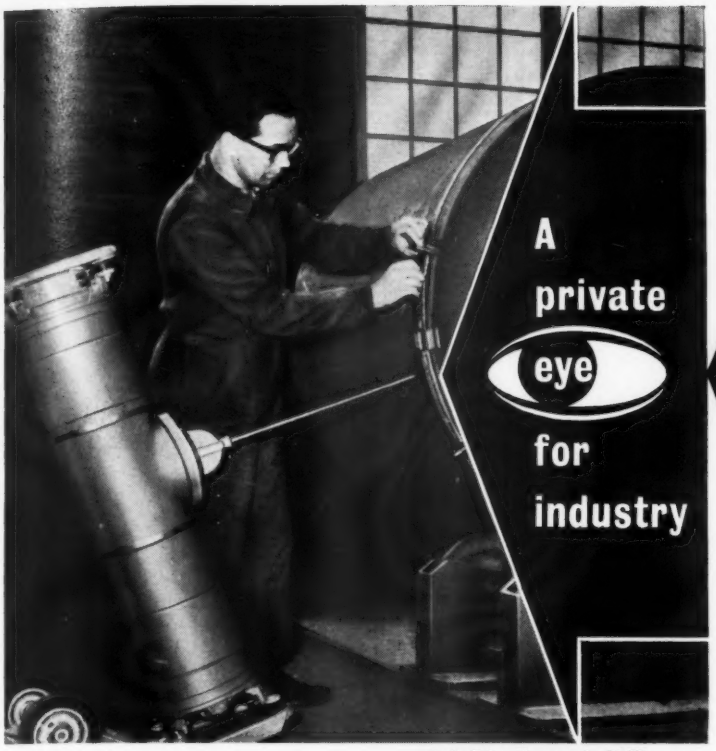


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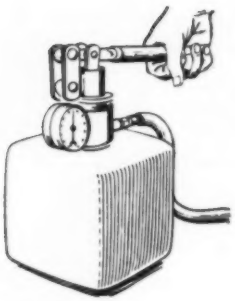
## *The* JUNIOR AIRHYDROPUMP



**Why labour at this?...**

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It automatically gives the *exact* pressure required and will maintain this pressure indefinitely, leaving the operator both hands free.
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Extension wingheads and formers can be supplied to increase capacity to 2½ and 3 inches.

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Hand operated hydraulic model for bending cold and unloaded 2 to 4 inch n.b. pipe.

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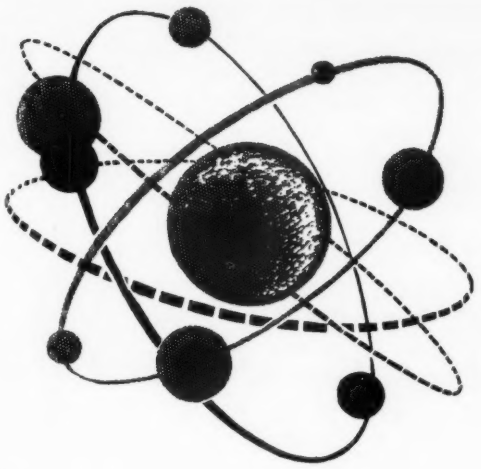

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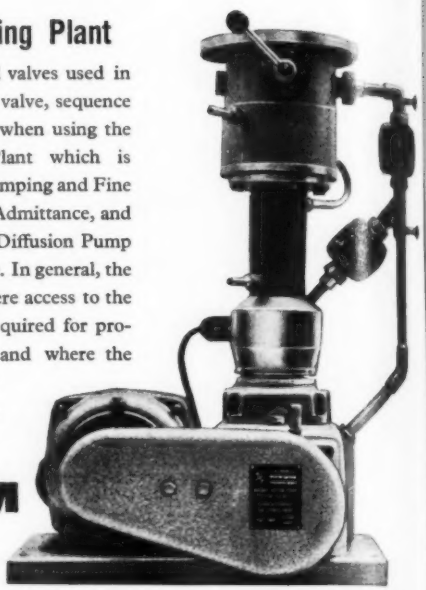
By means of the two hand valves used in conjunction with the baffle valve, sequence pumping may be obtained when using the Type HCU Pumping Plant which is equipped to give Rough Pumping and Fine Pumping, isolation or Air Admittance, and water relay to protect the Diffusion Pump against water supply failure. In general, the HCU. s more suitable where access to the vacuum chamber is not required for production sequence cycles, and where the plant is not likely to be left running overnight without supervision.



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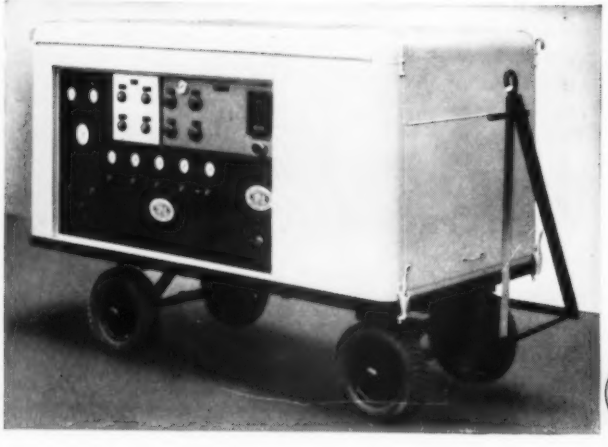

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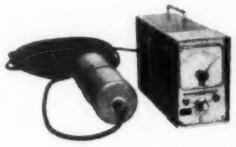

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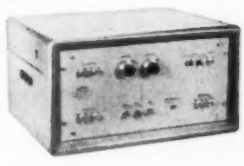

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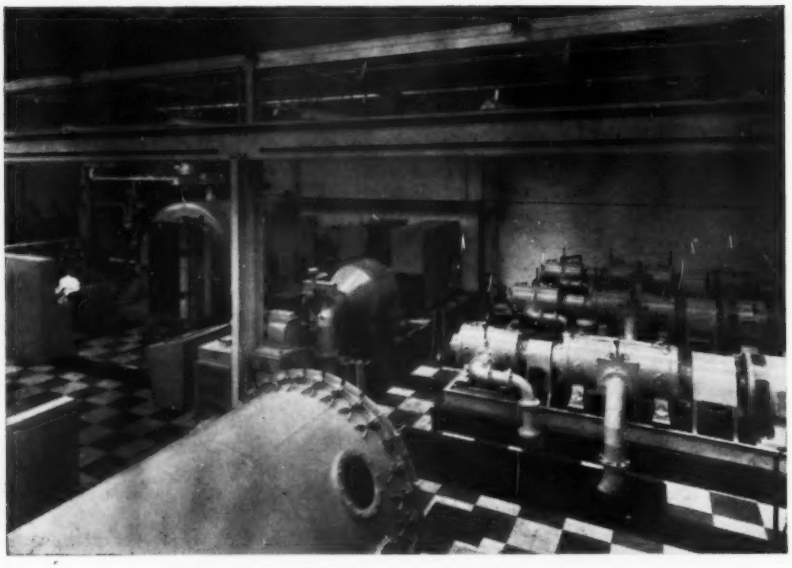

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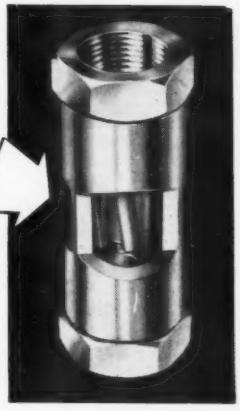
# See the flow with the 'Telicator'



Both low and high pressure systems can be fitted with a Telicator Visual Flow Indicator, which is a simple instrument for indicating the flow, whatever the viscosity. The rotors are specially designed by Dukes and Briggs to give the clearest indications over specific ranges of flow rate. Water supplies for cooling purposes and forced lubrication systems are two typical applications. A new model is under development for use with opaque fluids, and special designs can be made to meet specific requirements.

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- *Simple design ensures complete reliability.*
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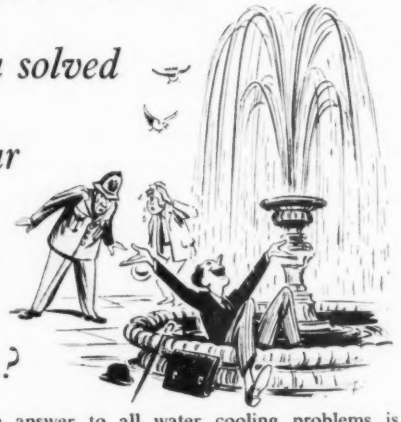

Undoubtedly, the answer to all water cooling problems is PREMIER. PREMIER Cooling Towers and Mechanical Water Coolers are among the most highly efficient and economical in the world—installed in many of the world's important works and power stations. PREMIER design and erect the plants, guarantee the performance and give a 100% after-sales service. Undoubtedly, the scientifically engineered construction and high efficiency and economy of PREMIER water coolers is the reason why they are acclaimed by engineers everywhere.

IT IS A FACT that the great economy achieved by PREMIER in increased efficiency, saving of water rates and space virtually pay outlay and installation costs.

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**WE** manufacture our own plants **WE** guarantee the performance

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Applications are invited for the posts of SENIOR LECTURER and LECTURER IN ENGINEERING (Mechanical). Preference will be given to candidates with a major interest in Applied Thermodynamics or Applied Mechanics, especially Theory of Machines. Some experience of Mechanical Design would be an advantage. University regulations permit teaching staff to read for the degrees of M.Sc. and Ph.D. The salary scales (at present under review) per annum are as follows: Senior Lecturer, £1700 to £2050; Lecturer, £900 to £1650. Membership of F.S.S.U. and Children's Allowance Scheme. Initial salary according to qualifications and experience. Applications should be sent not later than May 7, 1960, to **The Registrar, The University, Manchester, 13,** from whom further particulars and forms of application may be obtained. Applications by airmail letter, in the first instance, will be considered from overseas candidates.

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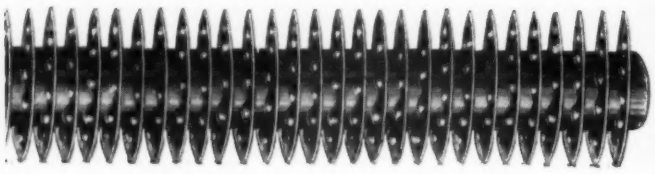

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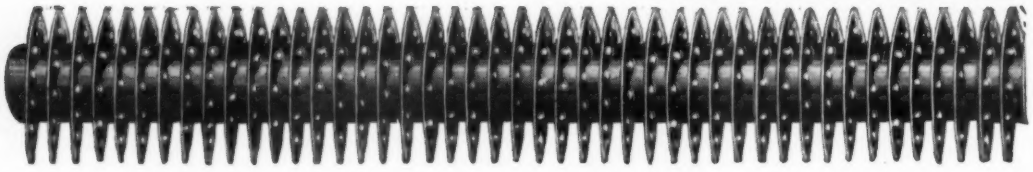

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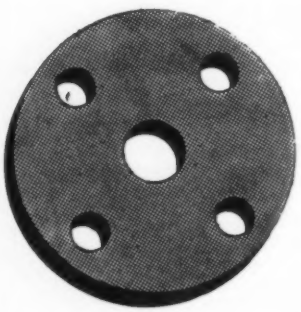

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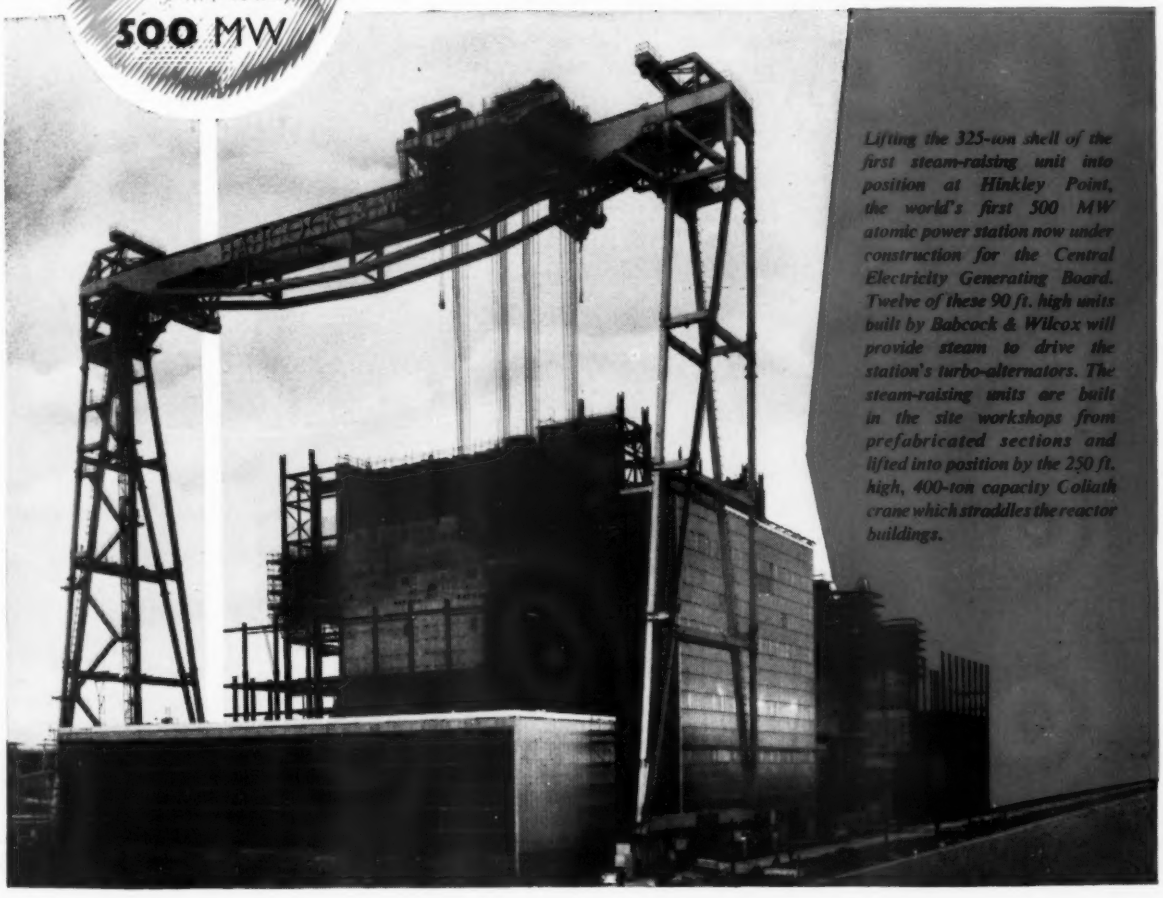

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